PAPER No. 123.

BITUMINOUS ROAD CONSTRUCTION IN THE PUNJAB.

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Introductory.

The object of this paper is to review briefly the progress up to date in providing road surfaces to meet the changing traffic conditions in the Province;

The road problem brought about by the rapid extension of motor traffic in other countries is now being forced upon this Province in a rapidly intensifying form, by the extraordinary popularity of the motor lorries which, usually greatly over-loaded, are now to be seen careering along the roads in all directions, and it can only be a matter of time before zemindars and market gardeners within a moderate radius of the larger towns will appreciate the value of motor transport for getting their milk, eggs, vegetables, fruit and other produce to market.

Original Experiments.

Road work in the Punjab is complicated by climatic conditions, in the shape of intense heat and drought, while the long distances that stone, suitable for metalling, has usually to be brought, present another difficulty, and consequently experiments are being tried both in the Nili Bar and on the Lahore-Bhakkar and Lahore-Harike roads to ascertain whether brick ballast is a possible substitute, while a sand carpet is also being tried at Fitna in the Bar.

The short length of brick ballast with bitumen mastic, laid in March 1924 on mile 306 of the Grand Trunk Road, was left unsealed and after 18 months traffic had become very uneven, while a longer section laid in Oct. 1924 on the Montgomery-Pakpattan Road, where the traffic was nothing like so heavy, showed that it could not stand direct contact with steel tyres, so that wherever brick is now used it is invariably given a sealing coat and covered with stone grit.

The short lengths of sand carpet or sand topping laid in mile 309 of the Grand Trunk Road in Dec. 1923 developed a very pronounced wave while the longer section laid on the Montgomery-Pakpattan Road in Oct. 1924 will be alluded to hereafter.

It was in Rawalpindi, however, that the growth in the cost of road maintenance and the dust nuisance consequent on the increase in motor traffic after the war first brought home the necessity for something better than water-bound macadam on the roads, and more especially on the road towards Murree.

Crude Oil.

The first experiment was to try, in Nov. 1922, the effect of crude oil on parts of the Mall and Mayo Road, but this only lasted from 3 to 6 months. Further experiments were carried out in the following Sep. with residue oil (Rs. 80 a ton, ex the Attock Oil Company's refinery at Morgah, three miles from Rawalpindi). This was more successful and kept the roads dustless for 8 or 9 months. At first, it also seemed to collect a thin paste of dust and oil on the surface, which protected the metalling, but later, when the oil had evaporated, pot-holes quickly formed and the metal began to work loose, while repairs in the ordinary way were found to be useless as the greasy metal refused to bind.

Mr. Stubbs, Executive Engineer, thereupon tried painting the surface with a mixture of 100 parts by weight of Trinidad asphalt to 23 parts of flux, and spreading over this, while still hot, a half-inch layer of half-inch limestone chips. The result was quite satisfactory and proved that bitumen would adhere to a previously oiled road. Unfortunately the cost was high, working out to about Rs. 7 per hundred sq. ft. mainly due to the high price of flux oil (Rs. 13/8/0 cwt.) and the difficulty of spreading the mixture thin enough on the surface. Mr. Stubbs found there was no particular advantage in rolling the limestone chips into the bitumen. More experiments followed, and ultimately he used spramex, and found that it adhered to the road surface just as well as a mixture of Trinidad asphalt and flux oil, while costing only Rs. 4/1/0 per hundred sq. ft. and this has since been used. The coat, applied with a mechanical sprayer in August 1925, is now showing signs of wear and is not expected to outlast another hot weather, but some done in April 1926 is still in good condition.

Tar-Bitumen Mixture.

Miles 1, 2 and 4 of the Murree Road, as well as the link road from the Queen's Statue to the railway bridge, were treated in 1925 almost throughout their entire lengths with a mixture of 60 per cent. bitumen and 40 per cent. tar, while in the third mile five furlongs were grouted and three furlongs painted with Trinidad asphalt and flux oil.

The main difficulty in applying this tar-bitumen mixture was that the bitumen had to be raised to a far higher temperature than tar for use on the road, so that either the tar was overheated and spoiled or, as more generally happened, the bitumen was not heated sufficiently to adhere to the road surface properly, and Mr. Stubbs reported that had he known of a bitumen as cheap and as easily applied as spramex he would not have tried this mixture. The International Road Congress, which met at Milan in 1926, however, has recommended a closer study of tarbitumen mixtures.

Mile 1 had to be repainted with spramex in May 1926 and is not expected to last another year. Practically all the repairs are on the side followed by the heavy traffic from the city. Mile 2 is, if anything more heavily trafficked, but though extensively repaired in patches it has not been completely resurfaced since it was coated with the tar-bitumen mixture in September 1925. The surface, however, is very bumpy and will not last another year. Mile 4 was in a hopeless condition a year after it was done, and traffic had to take to the berms. It was remetalled and coated with spramex at the end of 1926, but the spramex is now shewing signs of breaking up. The link road from the Queen's Statue was re-coated with spramex in April, 1926 and though wearing well is apt to break up at the edges, partly owing to want of lateral support and perhaps partly to damp from the berms working in underneath the metal, or dust from the berms getting into the spramex and making it brittle.

Trinidad Asphalt and Socony Bitumen.

Trinidad asphalt is obtained from the so-called Pitch Lake in Trinidad and, when refined, contains about 56·5 per cent. of pure bitumen, 7·5 per cent. of organic matter, and 36 per cent. of finely divided mineral matter. The flux oil with which it is softened is a thick, viscous, non-volatile oil, recovered from petroleum by distilling off the light volatile products present in crude petroleum. Socony is the residual bitumen, prepared in the same way by the Standard Oil Company of New York (hence the name) from petroleum.

In 1925 an experiment was made in mile 3 of the Murree Road to test the relative merits for grouting of Socony bitumen and Trinidad asphalt with a flux oil and as similar experiments were made in the Second and Third Circles of the Buildings and Roads Branch, Public Works Department, it will be convenient to consider these together and compare results.

Rawalpindi Experiments.

Five furlongs of mile 3 of the Murree Road were done between March and June—2,100 linear ft. with Socony bitumen and the rest with Trinidad asphalt. In both cases the grouting was done on 3 in. of quartzite metal broken to 2-in. gauge. This was laid to template on the old surface, which had been nicked at 9-in. intervals with a pickaxe and thoroughly cleaned. It was then lightly rolled with a 12-ton roller to tighten up the metal, but still leaving the surface very open.

For the first section a mastic was made of equal parts by weight of Socony bitumen and Sohan sand, separately heated in cans and open pans to a temperature of 200 degs. F. and then mixed and well stirred while further heated to a temperature of 350 degs. F. This was then poured on the road in diagonal strips, 9 inches wide, at the rate of $1\frac{1}{4}$ gals. to the sq. yd., $\frac{1}{8}$ gals. being kept back for hungry spots. Sufficient $\frac{1}{2}$-inch quartzite grit was then spread to cover the surface and fill any interstices, and was rolled until there was no further movement.

Before dry-rolling the second section, 10 per cent. of ¾-inch to 1-inch chips were spread over the surface to fill the interstices. A mixture of 100 parts by weight of refined Trinidad asphalt and 23 parts of flux oil was then prepared, and continually stirred while being heated to a temperature of 325 degs. F. This was poured in the same way as the Socony mastic at the rate of one-and-a-half gals. to the sq. yd. This done, the surface was covered with ½-inch limestone chips, and again rolled till all movement in the metal ceased.

In neither case was a sealing coat originally proposed, as it was argued that in a dry climate like that of the Punjab complete water-proofing was unnecessary. The bitumen was also expected to work-up in time and itself seal the surface. This, however, did not occur, and the surface remained rough and unprotected, though the second section, owing to a certain amount of crushing in the rolling, presented a much better appearance than the first section where Socony mastic had been used.

A short length, however, in each section was sealed with the material used for grouting, and these lengths are still, after 2½ to 3 years, in excellent order, and have needed practically no repairs. The rest of the five furlongs have recently been sealed, and the Executive Engineer in charge (Mr. E. S. Heard) is of opinion that this bit of road should stand up to the heavy traffic it has to carry for some years yet.

The two methods being compared, the Socony mixture cost Rs. 22/8/0 per 100 sq. ft., the Trinidad asphalt and flux oil, Rs. 36/11/0, but the mixing was a slow and laborious process and it was difficult to ensure either uniform distribution or complete penetration. According to Mr. Stubbs, the Trinidad asphalt was standing up to the traffic better than the Socony mastic when the sealing coat was applied, while the mastic was showing signs of disintegration.

A 4½-inch coat of water-bound macadam would cost about Rs. 7 per 100 sq. ft. to lay in this mile, but its life would not exceed two years.

Gurdaspur Experiment.

In the Third Circle the experiment was tried on furlongs 3 to 8 of mile 44 of the Amritsar-Baijnath Road in April 1925. In this case a coat of 3 inches of Pathankot quartzite, broken to 1½-nch gauge, was laid on the road, and while three furlongs were grouted with Trinidad asphalt mixed with flux oil (4 : 1), the other three were grouted with a mastic consisting of equal parts of Socony bitumen and sand,—1¼ gals. of Trinidad asphalt being used per sq. yd. as compared with 1¾ gals. of mastic. The costs were Rs. 33/8/0 per 100 sq. ft. for the Trinidad asphalt as compared with Rs. 26 for the Socony mastic. It is only now that the road is showing signs of disintegration under the bullock-cart traffic from the railway station, and some patching, with a sealing coat has become necessary. In this mile a 4½-inch coat of water-bound macadam cost about Rs. 11 per 100 sq. ft.

Jullundur Experiment.

The Second Circle tried two experiments, both on heavily trafficked sections of the Grand Trunk Road, one in Jullundur, the other in Ambala. It was feared that the Jullundur experiment would not be altogether successful, as a proportion of the stone proved to be very soft and easily crushed under the roller. It was, however, picked out as far as possible. The experiment was tried on the bit of road past the district courts and the city, where the traffic is extremely heavy, and so far, although the road has now been down two years, there are no signs of disintegration. Four furlongs were laid with Trinidad asphalt and six with a mastic composed of Socony bitumen and sand, mostly in equal parts, but in the first furlong of mile 229 the proportion of bitumen to sand was varied in three lengths to 4:3, 4:2 and 4:1. The surface is still intact, but unfortunately the costs of the different kinds of work have not been separately maintained.

Ambala Experiments.

In Ambala, more trouble was taken than elsewhere to obtain comparative results, lengths of Socony bitumen and sand mastic, on stone metal broken from boulders brought from the bed of the Ghaggar at Chandigarh, alternating with lengths of the same metal grouted with Trinidad asphalt, and also with lengths of Delhi quartzite similarly treated. Most of the work was done under the direct supervision of a subordinate, with previous experience of this class of work, who was lent by the Road Engineer for the purpose, while the local Executive Engineer also took a keen personal interest in the experiment and was constantly on the work—yet it was a failure. Pot holes began to form at an early stage and now after a life of only two years it is about to be entirely renewed. It is possible that in digging up the old surface the reason for its early failure may come to light.*

In the hot weather of 1926, furlongs 1 to 3 of mile 121, opposite the Cantonment Railway Station, were increased in width from 16 to 24 ft. Brick kerbs, backed by earth (on one side a foot path) were provided along both edges. The old metalled surface was then carefully scarified and re-sectioned from kerb to kerb, the berms being replaced with 6 inches of hand-packed brick soling. A 3-inch coat of Delhi quartzite, broken to 2½-inch gauge, was then spread over the whole width, rolled and grouted with mexphalte, which was poured by hand at the rate of 1·5 gals. to the sq. yd. Over this was spread sufficient Chandigarh gravel (¼ inch—¾ inch) mixed with screenings, to fill any interstices, and the rolling continued till the surface was thoroughly consolidated. The surface was then swept clean of all loose material and sealed with spramex applied by means of a Weeks sprayer at the rate of half-a-gal. to the sq. yd. This was immediately followed by a coat of gravel, varying from dust to ¼ inch, which was also rolled before the road was opened to traffic. This has proved quite satisfactory, and the surface is standing up well to the heavy traffic from the railway station and goods yard.

* Five hundred square yards of Sangla stone on the Lyallpur Jaranwala Road, grouted with a mastic made of equal parts by weight of Socony bitumen and canal silt in March 1924 also proved a failure and pot holes began to form within 18 months. This failure was attributed to the lamination of the stone.

Lahore-Mianwali Road.

Between Chuhar Kana and Pindi Bhattian on the Lahore-Mianwali (Arterial No. 2) Road about 14 miles have been grouted,—a mile and a half with Socony bitumen, sealed with the same material, and the rest with mexphalte sealed with spramex. Over the first five miles was spread an inch of Sangla-Hill grit, from $\frac{1}{4}$ to $\frac{3}{4}$-inch gauge, while Pathankot or Jammu gravel was used over the rest. Pathankot gravel however, was preferred to the Jammu stone as, being better graded, it required less spramex.

The road had been allowed to fall into a complete state of disrepair before it was taken over by the Public Works Department and there were deep ruts to be filled up before the metal could be spread for grouting. It will be noticed from the analysis of rates (Appendix A) that the work done in the cold weather required a greater quantity of bitumen for sealing than was necessary when the weather was warm.

Lahore-Bhakkar Road.

Beyond Sharakpur, on the new artery through Lyallpur, owing to the distance from the nearest railway station, stone would have proved so costly (Rs. 59 per 100 cub. ft. being the average rate for fifteen miles) that it was decided to use specially hard burnt brick, broken to a two-inch gauge, bitumen-grouted, sealed and gritted with Pathankot gravel. At an early stage in the work, however, ruts appeared, and it was feared that the experiment would prove a failure, but as time went by these ruts partially disappeared under the light traffic. It yet remains to be seen how it will stand up to the heavy traffic which may be expected once the road is opened to Lyallpur. In Lucknow *kankar* was successfully grouted, but this has not proved to be a great success.

Lahore-Moga Road.

In miles 18 to 29 of this road the intention is to use brick ballast grouted with mexphalte,—the specification for the work being almost identical with that used on the Lahore-Bhakkar Road.

Well burnt to over-burnt bricks are broken to $2\frac{1}{2}$-inch gauge, and spread to an unconsolidated thickness of $3\frac{1}{2}$ inches, *i.e.*, a 3-inch coat with $\frac{1}{2}$-inch extra to fill up low places in the soling. This is lightly rolled with a 10-ton roller, and the mexphalte, heated to a temperature of 350 degs. F., is then poured over it at a uniform rate of 1·7 gals. to the sq. yd. Pathankot gravel, which has passed a $\frac{3}{4}$-inch screen, but has been held up by a $\frac{3}{8}$-inch screen, is then at once spread over the grouted ballast, and the whole thoroughly consolidated by a 10-ton roller, additional gravel being added wherever the bitumen is exposed. Progress in rolling is at the rate of about a furlong of 9-feet-wide road a day.

The surface is brushed clean for the spramex (heated to a temperature of 350 degs. F.) to be sprayed over it. The gravel which has passed the $\frac{3}{8}$-inch screen, but has been held up on a $\frac{1}{8}$-inch, is then spread over the spramex and lightly rolled to press it in—progress being at the rate of two furlongs a day.

Mr. Freak, the Executive Engineer in charge, is also trying a tar-pitch mixture on this road, but it is yet too early to say with what measure of success, or how the price is going to compare with bitumen.

Nili Bar.

Bitumen has been used more extensively and under more varied conditions in the Nili Bar than elsewhere in the Province, and I am indebted to a note by Mr. Stubbs for the information I have been able to place before the Congress.

The reason why so much bitumen work was done in the Nili Bar was that as the roads there were being constructed ahead of the canals, and without canal water, it was impossible to build water-bound macadam roads in a practically rainless region. As the canal water courses are extended, however, water-bound macadam is being used as it is felt that any money which can be made available for bitumen is far more urgently needed to improve the much more heavily trafficked roads round the provincial centres of trade and industry.

Up to the end of October, in the portion of the Nili Bar directly under the charge of Mr. Stubbs, nearly 22 miles of road had been laid with limestone, 13 miles with Pathankot quartzite, 4 miles with Sangla-Hill stone and about 10 miles with brick ballast—natural (Trinidad) asphalt was used for 15 miles—residual (Socony) bitumen for 5 and mexphalte for the remaining miles. A sealing coat was only given in those miles in which brick ballast was used and this was covered with stone chips.

Method of Laying.

Except that a 10-ton tandem roller was used in the case of the brick metal, in place of the 10-ton three-wheelers used elsewhere, the process for grouting with all classes of bitumen and metal was practically the same—

(a) Brick-on-end edgings, $4\frac{1}{2}$ inches wide, 6 inches buried in the ground and 3 inches projecting above the level of the soling, were laid a day in advance of the grouting.

(b) Three inches of metal, broken to 2-in. gauge, were then spread to a camber of 1 in 72 on the flat-brick soling. This provided an average thickness of $3\frac{1}{2}$ inches at the crown and $2\frac{1}{2}$ at the edges.

(c) The metal was rolled dry to compact the surface *thoroughly* without unduly closing up the interstices.

(d) A very careful check was next made, both longitudinally and transversely, to ensure a true surface, as after this stage inequalities cannot easily be removed and any depressions must be made good with fine metal before grouting.

(e) Bitumen heated to a temperature of 350 degs. F. was then poured, at the rate of 1·5 gals. per sq. yd. in the case of residual bitumen, and 1·34 gals. in the case of the Trinidad asphalt,—the latter having been first mixed with 23 per cent. of its weight of flux oil.

(f) While the bitumen was still hot $\frac{1}{8}$ inch to $\frac{3}{4}$ inch grit was spread over the surface, at the rate of 4 to $4\frac{1}{2}$ cub. ft. per hundred sq. ft. of surface, and immediately rolled till all movement ceased. It was found that a roller could consolidate 500 to 600 sq. yds. a day, depending on the number of working hours.

Various Kinds of Grit.

Various kinds of grit were used; screenings from quartzite metal; limestone screenings; a mixture of these; machine-crushed limestone chippings from Wah as well as from Warcha. The machine-crushed chippings from Wah were clean and sharp and gave excellent results. There was too much variation in the gauge of the quarry sweepings from Warcha, but where the gauge was correct the results were even better than those of Wah. The screenings were too fine to key securely into the interstices of the metal, and tended to produce a dusty road. Limestone chippings were preferred to quartzite, giving a more compact surface. Overburnt-brick chips were used over brick metal in grouting, but as already mentioned the sealing coat was covered with stone chips.

Sealing Coat.

Opinions are divided whether a sealing coat should be laid immediately after the grouting is completed or not. Manufacturers and text-books generally consider it advisable, but in the Nili Bar 3 or 4 months were allowed to elapse before sealing the surface, and this was found to be quite satisfactory. The quantity used was 0·3 gal. per sq. yd.

Sand Carpet.

In Nov. 1924 Mr. K. G. Mitchell laid a length of 862 ft. of sand carpet in mile 15 of the Montgomery-Pakpattan Road, to ascertain whether it was possible to make a road with a mixture of the local sand and bitumen. Sand with 10 per cent. socony bitumen added was heated to a temperature of 350 degs. F. in open pans and cauldrons and laid as a 2-inch carpet over a cambered, $7\frac{1}{2}$-inch, brick on edge on flat brick, soling coat. The carpet was rolled with a 10-ton, three-wheeled roller to a thickness of $1\frac{1}{2}$ to $1\frac{3}{4}$ inches. This gave a surface which did not soften appreciably in the hot weather and is still in very good order. The actual cost of this experiment is not known, but Mr. Stubbs has estimated that the cost per mile for a 12-ft. width works out to about Rs. 8,500 as compared to about Rs. 15,000 for a coat of water-bound macadam, with the long lead for the stone from the railway at Montgomery.

Asphalt Mixing Plant.

A 5-ton capacity asphalt mixing plant has since been obtained at a cost of Rs. 75,000. When it was started some difficulty was experienced in arriving at a workable mixture. Eventually, an addition of 12 per cent. Trinidad asphalt without filler seemed to give the best result, and was therefore adopted. At first this seemed quite satisfactory, but recently fine cracks have appeared which are causing anxiety. Various reasons

have been assigned for these, such as the insufficient thickness of the coat itself, (it is only 1 inch thick, and owing to the unevenness of, and the absence of camber in, the 4½-inch brick-on-edge soling, the thickness is reduced to ¾ inch in places) the mix being too cold when laid, and the operation of the plant defective. Even so, the cost worked out to Rs. 8,400 a mile of carpet, 12 feet wide, or practically the same as that of Mr. Mitchell's 1¾-inch carpet with residual bitumen. The success of of any road surfacing however depends largely on its foundation which must be regular and even in contour as well as of adequate strength and it seems more than doubtful whether a 4½-inch brick soling, with a 1-inch carpet over it, is going to withstand impact from lorry traffic. Experiments are now being tried again with residual bitumen, and it may be that Mr. Harris, the engineer in charge, will be able to tell the Congress with what result and whether the expensive plant obtained for the work is likely to justify itself.

Dipped and Grouted Bricks.

The use of broken-brick ballast with bitumen suggested the possibility of using as a pavement whole bricks, laid on edge and grouted. This, however, was found to use more bitumen than was required for a 3-in. coat of broken brick—partly because of the greater depth of the joint, and partly because the bricks had to be laid with wide joints for the bitumen to flow into them. Laying bricks, previously dipped in bitumen, as close together as possible, and filling any joints with sand before sealing the surface, was also tried, and a further experiment with bricks 6-in. by 3-in. by 2-in. which can be more thoroughly burnt than standard size bricks, is now about to be tried.

Spramex.

Spramex has been tried as a surface dressing on several roads in Lahore, where the cost, including gritting, works out to Rs. 5/-per 100 sq. ft. for a first coat and Rs. 3/4/- for the subsequent coats, as compared with Rs. 3/8/- or Rs. 3/9/- for a first coat and Rs. 1/10/- to Rs. 1/12/- for each succeeding coat of road tar—a 4½-in. coat of water-bound macadam (Serai-Kala limestone) costing Rs. 12/4/- per 100 sq. ft. on these roads. Spramex is softer than tar and therefore less liable to become slippery, but slipperiness can largely be overcome by spreading fine grit over the tar as it is applied. Moreover tar does not spread on to the beams as spramex is found to do in the hot weather. The Executive Engineer, after comparing the wearing properties of the Shalamar No. 1 road tar used in miles 299, 301, 302 and 304 to 309 of the Grand Trunk Road with the spramex over the old tarred surface in miles 311 and part of 312, is of opinion that the tar lasts better, but that there is a tendency for the edges unprotected by a kerb to break up in miles where the width is only 12 to 16 ft. due to the tendency of the lorry traffic to hug its own side of the road. This also results in a depression being formed down the centre of miles surfaced with only water-bound macadam.

Jail Road.

In Lahore, on Jail Road, between the Central Jail and the canal bridge, there is very heavy traffic of narrow-tyred bullock carts taking bricks to the city. This road was sealed with spramex and gritted with Pathankot

gravel between December 1925 and February 1926, and though the side of the road, along which the empty carts return, is still standing up to the traffic, that on the other side, along which the loaded carts travel, started to peal off in patches after three months' wear. The suggestion was made that perhaps the road surface had not been properly cleaned before laying the spramex. To disprove this, the spramex was removed, the surface of the metal very carefully cleaned and a fresh coat of spramex given, but the result was the same as before, a section of the road was then carefully patched, where broken, and given a second coat of spramex over the whole width, but with no better result. Finally the theory was propounded that the original water-bound macadam had been blinded with earth during consolidation, and that the earth working out forced up the sealing coat. To disprove this, last May, a strip 700 ft. long and 6 ft. wide on the more heavily trafficked side of the road was scarified, the metal screened, and new metal added after eliminating all dirt. This was consclidated without the addition of any earth, spramexed and gritted, but it has now become patchy, as has also another length which was relaid, and given a coat of tar before being spramexed. The effect of a preliminary coat of crude oil before applying the spramex was equally unsuccessful in prolonging the life of the spramex. In places this has collected into ridges over an inch thick while elsewhere it has shrunk to a mere skin which is fleking off. L. Sant Ram, the Executive Engineer in charge of this work, opened out several patches where the spramex was inclined to peel and in every case found a layer of white dust between the sealing coat and the metal. It would appear from this that the narrow wheels of the bullock carts have abraded the stone through the spramex, thereby forming a dust coat between the latter and the stone.

The road along the canal bank between Jail Road and Ferozepore Road was spramexed in February 1926 over a previously tarred surface, and is wearing well, but bullock carts are not allowed to use it.

McLeod Road.

McLeod Road, from milestone 310 (Braganza's Hotel) to its junction with the Mall opposite the General Post Office, after having been tarred for many years, was given a coat of spramex in May 1926, but though not so heavily trafficked as Jail Road, it carries a considerable volume of heavy traffic, and on three occasions since it was first laid extensive repairs have been necessary to the side which carries the heavy carts coming from the railway station. This road surface is not expected to last through another hot weather.

Grand Trunk Road.

On the Grand Trunk Road, between the Bhati Gate and the octroi post, north of the Chota Ravi, a coat of spramex was tried in June 1926 over the previously tarred surface, but this very quickly broke up along the side next the city under the heavy timber traffic from the river. This has just been relaid with bitumen-grouted limestone metal similar to the Ravi Bridge approaches.

These approaches, for just under half a mile on the south approach (width 28 ft.), and for over a furlong (24 ft. wide) on the north approach, were relaid a year ago with 3 in. of Serai-Kala limestone metal (2-in. gauge), penetrated with 1·5 gallons per sq. yd. of mexphalte, and finished off with 0·3 gallon per sq. yd. of spramex, and gritted. This actually cost over Rs. 28 per 100 sq. ft. to complete, and the result seemed satisfactory, but marked waviness has since been produced on the side of the south approach by which the heavily loaded carts, proceeding citywards, leave the bridge.

The analysis of the cost per 100 sq. ft. of spramexing a water-bound macadam road is as follows :—

Item.	Rate.	First Coat.		Second Coat.	
		Quantity.	Cost.	Quantity.	Cost.
			Rs. a. p.		Rs. a. p.
Spramex ..	Rs. 8/- per cwt.	3·7 gals. = 38·8 lb.	2 12 0	2 gals. = 21 lb.	1 8 0
Pathankot gravel	Rs. 30/- per 100 cub. ft.	2·5 cub. ft.	0 12 0	2 cub. ft.	0 10 0
Fuel, lubricants, brushes and sundries ..	..	..	0 7 0	..	0 5 0
Carriage of material to site of work ..	..	..	0 3 0	..	0 2 0
Labour for cleaning road surface, heating and spreading spramex, gritting and rolling ..	..	..	0 13 0	..	0 10 0
Total ..	..	..	4 15 0 say 5 0 0	..	3 3 0 say 3 4 0

In the Nili Bar, where a sealing coat was used over brick ballast, the cost per 100 sq. ft. worked out as follows :—

	Rs. a. p.
Bitumen 35 lb. at Rs. 6/8 per cwt. ..	2 0 9
½-in. stone chips. 4 cub. ft. at Rs. 3 per 100 cub. ft.	1 3 3
Labour and fuel in heating and spraying ..	0 12 0
Total ..	4 0 0 per 100 sq. ft.

Tar Spraying.

In Lahore itself tar is also used as a surface dressing for water-bound macadam, tar, in accordance with the British Standard Specification for No. 1 road tar, being obtained from the Shalimar tar distillery. When it was first tried the rate f. o. r. Howrah was Rs. 170 a ton, but on account of leakage in transit, etc., it actually cost Rs. 250 a ton at the roadside. English tar was also tried, but proved more expensive.

The process consisted of sweeping all the dust off the road with stiff wire brushes, and then, with rubber squeegees, spreading the boiling tar over the surface. This was then sprinkled with grit and allowed to set for thirty-six hours, after which it was covered with a thick layer of fine sand and opened to traffic. A week later the sand was removed. The surface, though dry and free from dust, proved smooth and slippery. The analysis of the cost per hundred sq. ft. was as follows :—

Item.	Rate.	Quantity.	Cost per 100 sq. ft.
			Rs. a. p.
Tar .. Rs.	12/8/- per cwt.	0·25 cwt.	3 2 0
Grit	40/- per 100 cub. ft.	0·5 cub. ft.	0 3 2
Sand	10/- per 100 cub. ft.	4 cub. ft.	0 6 5
Fuel for heating ..	1/8 per maund	0·05 maund	0 1 2
Labour on spreading and brushing	-/3/3 per 100 sq. ft.	..	0 3 3
Sundries such as brooms, etc.	-/2/- per 100 sq. ft.	..	0 2 0
.. Total cost per 100 sq. ft.		.. .. ..	4 2 0

Only 0·1 cwt. was required per 100 sq. ft. for succeeding coats, while the labour, etc., remained practically the same and consequently the cost worked out to Rs. 2/4/- per 100 sq. ft.

With tar delivered on the roadside, as it should have been, for Rs. 200 a ton, the rates for first and succeeding coats would have been Rs. 3/8/- and Rs. 1/12/-, respectively.

In 1923 a Fowler roller with a revolving brush and sprayer attachment, and a gritter on wheels to be drawn by the roller, when required, was obtained and has given satisfactory results, except that the revolving brush does not give a sufficiently clean surface and has to be supplemented with sweeping by hand.

The tank of the sprayer holds 8 cwt. of tar, and when the machine works at top gear it sprays (any width up to 8 ft.) 1,300 sq. ft. per cwt. of tar, (0·08 cwt. per 100 sq. ft.) and at low gear 800 sq. ft. (0·125 cwt. per 100 sq. ft.). The gritter holds 120 cub. ft. of grit and spreads a layer about $\frac{1}{8}$ in. thick over the sprayed surface, but this can be varied.

The grit being spread, the roller is passed over the surface and the road thrown open to traffic the next day, any places where the tar is visible having been covered with a little fine sand. A week later all surplus grit and sand is swept up, leaving a smooth, dry, dustless road, which is not slippery.

The tar is now railed up during the cold weather, in steel barrels, duly insured, in covered trucks. This practically eliminates any leakage and the cost of the tar on the roadside is now as follows :—

	Rs.	A.	
Tar f. o. r. Lahore	160	0	a ton.
Insurance @ 1 per cent.	1	10	,,
Cost of steel barrels, repairs, etc. ..	10	0	,,
Railway freight and cartage of empties ..	16	0	,,
Carriage from railway station to roadside and handling	6	6	,,
Total cost per ton at roadside	194	0	,,

At this rate the cost per 100 sq. ft. of tarring water-bound roads works out as follows :—

Item.	Rate.	First Coat.			Second Coat.			
		Quantity.	Cost.		Quantity.	Cost.		
			Rs.	a. p.		Rs.	a.	p.
Tar ..	Rs. 9/11/- per cwt.	0·25 cwt.	2	7 0	0.08 cwt.	0	12	6
Grit ..	,, 40/- per 100 cub. ft.	1 cub. ft.	0	6 6	1 cub. ft.	0	6	6
Sand ..	,, 8/- per 100 cub. ft.	2 cub. ft.	0	2 6	2 cub. ft.	0	2	6
Fuel and labour in heating and rolling ..	..	..	0	9 0	..	0	4	6
Total cost per 100 sq. ft.		First coat	3	9 0	Succeeding coats.	1	10	0

The United Provinces' experience has been that nothing less than two coats of tar are of any use—the second being given within six months of the first. There experience has also shewn that, while bitumen painting on kankar is unsatisfactory, tar painting gives good results.

It is now ten or eleven years since the Lahore Mall was first tarred and twleve to fourteen years since it was last remetalled. Opposite the shops it is retarred every year, but from Charing Cross on towards cantonments it has not been tarred for the past two years.

Spraymulsion.

Spraymlusion is now being tried on the first 3½ furlongs of mile 306 of the Grand Trunk Road. The emulsion is supplied ready for use in three grades, a bitumen emulsion, a tar emulsion and a combined tar and bitumen emulsion. It requires no heating or mixing. The cost per 100 sq. ft. applied to the road is less than the cost of spramexing and the result of the experiment will be watched with interest.

Advantages of Bitumen.

The advantages in the use of bitumen are many. It provides a road surface which will stand up to modern traffic much better than water-bound macadam and therefore, despite its initial cost, in the long run it is likely to prove economical ; it is dustless—no small consideration in a country where a car, travelling at speed, will leave a trail of dust a mile long behind it, to the discomfort and danger of all other traffic using the road ; it provides a smooth, impervious surface which soon dries after rain and it is comparatively noiseless and is easy to maintain. Its disadvantages are, its tendency to corrugate ; its unsuitability for steep gradients, and a difficulty in ensuring uniformity in the material. Its slipperiness has, to some extent, been overcome.

Road Corrugation.

Corrugation in the surface of a road is attributed to a variety of causes. It is claimed that it is not essentially a surface deformation, but is due to unevenness in the bearing value of the subsoil, or to the foundation coat being too light, or not having been sufficiently consolidated and therefore not sufficiently rigid. Unskilful rolling during consolidation is frequently responsible for the initial waves which are subsequently accentuated by the rhythmic pounding action of the traffic—especially motor traffic with its almost universal back-axle drive.

Leeming, in his book on 'road engineering'* points out that the formation of waves in tar-macadam roads is brought about by the fine, tarred, topping course moving backwards and forwards into waves, while the base course of larger material is worn bare in the hollows. Rear-axle-driven vehicles with solid rubber-tyred wheels are particularly prone to push the tarred topping backwards and forwards into waves, and at the same time grind down the lower course, so that, in the case of tar-sprayed roads, it is important to apply chippings and sand sparingly, in order that the finished coat may be kept as thin as possible to produce only shallow waves. With periodic applications of tar and chippings,

* "Road Engineering," by E. L. Leeming, pp. 188-90.

corrugation becomes a serious matter, especially in a warm climate, and where traffic is concentrated in streams by reason of the limited width of the roads. In such cases waves may be set up in both longitudinal and transverse directions, the traffic squeezing the topping to the sides as well as forcing it into waves, which are consequently most prominent along the edges of the road. Such waviness, once it becomes too pronounced, can often be remedied by removing the fine material from the ridges. It will often be found that the large aggregate underneath does not need renewal.

Water-bound macadam is seriously affected by the weather. With continuous wetness, or under standing puddles, moisture penetrates, and not only facilitates the movement of the stones against one another, but also softens them in proportion to their permeability and thereby accentuates the attrition caused by the passing traffic. Prolonged drought, on the other hand, causes the binding material to become loose and pass off in dust when the stone in the body of the road moves about under the influence of the traffic, and the smaller material goes to form the transverse ridges, while the larger stone remains in the trough of the wave. This is accompanied by the formation of pot holes, and disintegration soon follows.

Spraying a water-bound road with tar or bitumen not only protects it from weather influences and helps to bind the surface, but it also takes the wear, while, by providing a smoother surface, it reduces the resistance to traction and consequently the reaction on the road.

Grouting further checks the entry of moisture and produces a cushioning effect which reduces attrition of the aggregate, but, to ensure the best results, care must be taken when dry rolling, to compact the aggregate sufficiently to secure interlocking and to close all voids where bitumen would otherwise be wasted, but not so heavily as to prevent the even penetration of the bitumen throughout the mass, necessary to coat uniformly each bit of aggregate with a film of bitumen.

Mr. Stubbs estimates that about 800 tons of material are required for a mile of 12-foot width of bituminous grouted road, 3 in. thick, and on the assumption that the lead does not exceed a mile and the surface remains unsealed, he estimates the relative cost of roads in the Nili Bar as follows :—

	Rs.
Brick ballast	11,450
Limestone metalling	13,200
Pathankot metalling	12,900
Sangla-Hill metalling	11,800
Water-bound macadam ($4\frac{1}{2}''$)	8,200

A sealing coat over a grouted surface is estimated to cost Rs. 2,500 a mile or Rs. 4 per 100 sq. ft.

Relative Costs.

On a comparison of some of the roads for which analyses are given at the end of this paper, it will be noticed that rates vary as follows :—

Name of Station.	Rate per Hundred Superficial Feet.		
	Water-bound macadam 4½-in. coat.	Socony mastic 3-in. coat.	Trinadad asphalt 3-in. coat.
	Rs. a. p.	Rs. a. p.	Rs. a. p.
Rawalpindi	7 0 0	22 8 0	36 11 0
Gurdaspur	11 0 0	26 1 0	33 8 0
Ambala	12 0 0	22 6 0	21 14 0
Ditto		Mexphalte ..	22 12 0
		Spramex ..	5 7 6
Jullundur	13 0 0	Average ..	26 4 0
		Spramex ..	8 2 0

so that, considering merely the direct initial cost, before it can be pronounced an economical proposition it will be necessary to show that a bitumen-grouted surface will last from three to five times as long as water-bound macadam at Rawalpindi, where metal is cheap, and twice or three times as long at other places, where metal is more costly. The actual annual cost of maintenance of each type of road must also, however, be taken into consideration in making a comparison, but before this can be done it will be necessary to procure far more accurate statistics regarding the cost of main tenance and the weight of the traffic than are at present available, as well as the convenience of the public in having a better and more hygienic surface, with freedom from dust and less frequent disturbance of the road surface, while there is also a definite saving in road establishment and machinery if resurfacing has only to be undertaken every seventh or eighth year, instead of every second or third year.

To ascertain the probable life of a road however takes time. There are two factors to be taken into consideration, the nature and weight of the traffic using it, and the climate of the country. The effect of traffic on a surface can be investigated fairly accurately on a special track, like the one at Teddington, but it is not so easy to reproduce the climatic effects in a similarly intensified form.

Traffic Census.

English practice is that once traffic exceeds 200 tons per yard width per day, water-bound macadam needs strengthening. Surface dressing is considered good enough for a traffic of from 200 to 500 tons (including 15 per cent. of heavy commercial vehicles) and three inches of tar macadam or bitumen grouting, surface-dressed each year, or six inches of cement concrete, which may or may not be similarly dressed, for mixed traffic up to 1,000 tons. For heavier intensities, compressed asphalt creosoted blocks, or granite setts are used.

This suggests the advisability of having a traffic census before deciding how to treat a road. In England the Ministry of Transport periodically takes such a census. In August 1925 one was taken at 4,603 points on the 24,000 miles of Class I roads outside the large centres of population.* The traffic passing each of these points, between 6 a.m. and 10 p.m., was counted and recorded for seven consecutive days, care being taken to avoid holidays, etc., when it might possibly be abnormal. The previous census had been taken in 1922. In that year nearly 28 per cent. of the returns were below 500 tons a day, whereas in 1925 less than 10 per cent. of the census points returned so low a tonnage. In the same period the percentage of untarred, water-bound macadam in England and Wales fell from 38 to 12. Experience on the Jail Road in Lahore suggests that where there is a marked difference in the traffic going each way, on opposite sides of the road, that travelling in each direction should be separately recorded. Had a census been taken of the traffic on Jail Road in 1925-26 it is probable that instead of spending money on spraying it, it would have been grouted. Further, it is only with the aid of accurate information regarding the weight of traffic using different roads that a reliable comparison can be made between the wearing qualities of the aggregates or the methods of constructing the roads.

Excessive Axle Loads.

Another matter suggested by the behaviour of Jail Road is the desirability of doing something to restrict the axle loads of carts. In England the county authorities are empowered to make regulations for the tyre widths of vehicles drawn by animal power, and, in the case of two-wheeled vehicles, these appear to vary from about a maximum of $1\frac{3}{4}$ tons gross load on a 2-in. tyre, to three tons on a 4-in. tyre. The laden brick carts coming from the kilns on Jail Road have 2-in. tyres, and weigh $2\frac{1}{4}$ tons. Loaded with *bhusa*, the weight may be as much as 3 tons, which is excessive for the metal.

Measurements of Wear.

The last point to be emphasised is the importance of taking actual periodical measurements to ascertain the wear of the surface, instead of waiting for marked deterioration to become apparent. This is particularly necessary in a case where metal of doubtful quality is being used, and it is desirable to obtain early information of its behaviour. This is usually done by straining a wire across the road at a given tension from standards fixed in cast-iron sockets, imbedded in concrete blocks of considerable area, on either side of the road, clear of the carriage way. Such measurements must, however, be taken in conjunction with a series of short longitudinal sections, from which the travel and growth of any waviness may be observed. In new roads, however, it is difficult to eliminate the effect of settlement in the formation from the recorded surface monvement.

* Report on the Administration of the Road Fund for the year 1925-26.

A perusal of the results tabulated in Appendix B produces a feeling of uneasiness whether work is everywhere being carried out on the right lines. On the Grand Trunk Road the 1½-in. sand carpet laid in Sept.-Oct. 1926 on an unusually good foundation is already practically worn out. Will not the 1-in. carpet in the Nili Bar on a weak foundation have an even shorter life once there is any appreciable traffic over it? The original experiments seemed to shew that a concrete surface would not stand up to bullock-cart traffic and that bitumen grouting offered a better chance. Experience in the United Provinces has been just the opposite to this, and the Chief Engineer, having laid 94,000 sq. yds. of 6 in. cement concrete roads in Benares, at a cost of Rs. 5/8/2 per sq. yd., with cement costing Rs. 42/- a ton at the factory, is so satisfied that concrete provides the only satisfactory solution for heavy, concentrated, cart traffic, that he is now laying a strip of about ten miles between Benares and Moghal Serai, and proposes laying another length between Cawnpore and Unao. In the United Provinces bitumen surfaces, whether pre-mixed or grouted, are found to rut and, curiously enough, this is more noticeable on 24 ft. wide roads than on 16 ft. roads—possibly due to the fact that carts can keep to their ruts without any interference from passing traffic on the wider road.

This all suggests that road building in the Punjab requires much closer study than it has hitherto received. Experimental work must be continued on a more scientific basis; the exact quantity of materials used and the cost of subsequent maintenance of each experimental length of new surfacing, laid on a public highway, must be as accurately recorded as the original quantities and the initial cost of laying; the weight of traffic passing over each experimental length must be accurately observed and carefully recorded, and the wear in the surface of the road scientifically measured at short intervals of time. It is only by systematic experiment on lines which have been elsewhere successful and carefully correlating the type of road to the type of traffic it has to carry and the maintenance charges to the prime cost, that a satisfactory solution is to be found to the road problems of this Province.

APPENDIX A.

Specifications and Analyses of the Cost of Different Road Surfaces.

I.—Trinidad Asphalt (unsealed) (Mr. S. G. Stubbs).

Position of work.	Date when laid.	Specification.	Analysis of cost per 100 sq. ft.	Rs.	a.
Rawalpindi— Murree Road. Furlongs 3-5 of mile 3. (1,481 linear ft. 20 ft. wide).	Mar. to June 1925.	Penetration 1·42 gall. of Trinidad asphalt (15⅓ lb.) with 23% flux oil (3½ lb). per sq. yd. of 3-in. quartzite metal broken to 2-in. gauge with ½-in. limestone grit spread over the penetrated surface but no sealing coat.	31 cub. ft. ballast @ 17/- per 100 cub. ft. ..	5	4
			8⅓ cub. ft. grit @ 13/- per 100 cub. ft. ..	1	1
			3 cub. ft. Haro sand @ 19/- per 100 cub. ft. ..	0	9
			170 lb. asphalt @ 11/3/- per cwt. ..	18	0
			40 lb. flux oil @ 14/13/- per cwt. ..	5	4
			Scarifying, sectioning and consolidation ..	1	11
			Labour and fuel in heating, mixing and applying ..	4	14
		Actual cost per 100 sq. ft. ..		36	11
		,, ,, ,, ,, sq. yd. ..		3/4/9	

II.—Socony Mastic (unsealed) (Mr. S. G. Stubbs.)

Rawalpindi— Murree Road. Furlongs 5-8 of mile 3. (2,099 linear feet 20 ft. wide).	Mar. to June 1925.	Penetration 1·3 gall. mastic consisting of equal parts by weight of Socony bitumen and Sohan sand on each sq. yd. of 3-in. of quartzite metal broken to 2-in. gauge with ½-in. grit spread over the penetrated surface, but no sealing coat.	25 cub. ft. ballast @ 17/- per 100 cub. ft.	4	4
			6¼ cub. ft. grit @ 2/10/- per 100 cub. ft. ..	0	3
			1½ cub. ft. sand @ 9/- per 100 cub. ft.	0	2
			140 lb. bitumen @ 10/8/- per cwt. ..	13	2
			Scarifying, sectioning and consolidation ..	1	11
			Labour and fuel in heating, mixing and applying mixture ..	3	2
		Actual cost per 100 sq. ft. ..		22	8
		,, ,, ,, ,, sq. yd. ..		2/0/6	

NOTE.—A gallon of Socony bitumen weighs 9·7 lb.

III.—Trinidad Asphalt (unsealed) (Lala Sant Ram.)

Position of work.	Date when laid.	Specification.	Analysis of cost per 100 sq. ft.	Rs.	a.
Amritsar-Baijnath Road. Furlongs 3-5 of mile 44 (12 ft. wide).	Apr. 1925.	Penetration 1·25 gall. (15⅝ lb.) of Trinidad asphalt with 25 per cent. of flux oil per sq. yd. of 3-in. of Pathankot quartzite broken to 1½-in. gauge, no sealing coat.	25 cub. ft. ballast @ 25/- per 100 cub. ft. ..	6	4
			6¼ cub. ft. *bajri* @ 40/- per 100 cub. ft.	2	8
			139 lb. asphalt @ 14/- per cwt. ..	17	6
			35 lb. flux oil @ 17/- per cwt. ..	5	5
			Consolidation ..	1	0
			Labour and fuel in heating, mixing and applying ..	1	1
	Actual cost per 100 sq. ft. ..		..	33	8
	,, ,, ,, ,, sq. yd. ..			3/0/6	

NOTE.—A gallon of Trinidad bitumen with flux oil added weighs 12·5 lb.

IV.—Socony Mastic (unsealed) (Lala Sant Ram.)

Position of work.	Date when laid.	Specification.	Analysis of cost per 100 sq. ft.	Rs.	a.
Amritsar-Baijnath Road. Furlongs 6-8 of mile 44 (12 ft. wide).	Apr. 1925.	Penetration 1·75 gall. (27 lb.) mastic consisting of equal parts by weight of sand and Socony bitumen on each sq. yd. of 3-in. of Pathankot quartzite broken to 1½-in. gauge no sealcoat.	25 cub. ft. ballast @ 25 /- per 100 cub. ft.	6	4
			6¼ cub. ft. *bajri* @ 40/- per 100 cub. ft.	2	8
			1½ cub. ft. sand @ 15/- per 100 cub. ft.	0	4
			150 lb. bitumen @ 1/- per cwt. ..	15	0
			Consolidation ..	1	0
			Labour and fuel in heating, mixing and applying ..	1	1
	Actual cost per 100 sq. ft. ..		..	26	1
	,, ,, ,, ,, sq. yd. ..			2/5/3	

NOTE.—100 lb. of Socony bitumen mixed with 100 lb. of sand produces 13 gallons of mastic.

V.—Mexphalte sealed with Spramex. (Lala Sant Ram.)

Position of work.	Date when laid.	Specification.	Analysis of cost per 100 sq. ft.	Rs.	As.
Grand Trunk Road approaches to Ravi Bridge in miles 3 and 4 (28 ft. and 24 ft. wide).	Dec. 1926 to Jan. 1927.	Penetration 1·5 gall. (15¾ lb.) of mexphalte with a sealing coat of 0·3 gall. (3 1/7 lb.) of spramex per sq. yd. on 3 in. of Serai Kala stone broken to 2 in. gauge.	25 cub. ft. ballast @ Rs. 30/- per 100 cub. ft.	7	8
			8 cub. ft. *bajri* @ Rs. 30/- per 100 cub. ft.	2	6
			17 gall. (177 lb.) mexphalte @ Rs. 8/- per cwt. ..	12	10
			3·3 gall. (35 lb.) spramex @ Rs. 8/- per cwt. ..	2	7
			Consolidation ..	1	0
			Labour and fuel in heating, mixing and applying ..	2	8
			Actual cost per 100 sq. ft. ..	28	7
			,, ,, ,, sq. yd. ..	2	9

NOTE.—A gallon of mexphalte or spramex weighs 10·5 lb.
Labour rate high on account of scarifying, etc.

VI.—Trinidad Asphalt sealed with Spramex. / Socony Mastic sealed with Spramex. } (Mr. B. H. Moss.)

Position of work.	Date when laid.	Specification.	Analysis of cost per 100 sq. ft.	Rs.	As.
Grand Trunk Road— Furlongs 5-7 of mile 228 and furlong 2 of mile 229.	Dec. 1925 to Feb. 1926.	Penetration 1·53 gall. Trinidad asphalt with 25 per cent. flux oil added (4:1) per sq. yd. of 3 in. Jaijon boulders broken to 2-in. gauge and sealed with 0·51 gall. of mexphalte per sq. yd.	Details were not kept from which the relative costs of the two kinds of asphalt penetration can be compared but the total cost of doing 106,257 sq. ft. was as follows:—		
			Labour—		
			Scarifying old surface 11,545 cub. ft. @ Rs. 2/8/- 100 cub. ft. ..	288	10
Furlong 8 of mile 228, furlongs 1 and 3-6 of mile 229.	Jan. 1926 to Mar. 1926 and finished in June 1926	Penetration 1·53 gall. of Socony bitumen (No. 104) with equal parts by weight of sand per sq. yd. of 3 in. of 2 in. gauge metal broken from Jaijon boulders. This was also sealed with 0·51 gall. of mexphalte to the sq. yd.	Supplying and screening grit, 324 cub. ft. @ Rs. 30/- per 100 cub. ft. ..	97	3
			Dressing and rolling sub-grade to camber 106,821 sq. ft. @ Rs. -/8/- per 100 sq. ft. ..	534	2
			Spreading metal to template 25,199 cub. ft. @ Rs. 2/- per 100 cub. ft...	504	0
			Screening grit from metal 4,126 cub. ft. @ Rs. 3/- per 100 cub. ft. ..	123	12
			Spreading grit 4,450 cub. ft. @ Rs. 2/- per 100 cub. ft.	89	0
			Rolling surface and grit 29,649 cub. ft. @ Rs. 4/- per 100 cub. ft. ..	1,186	0
			Heating, mixing with sand and applying Socony bitumen, 289 cwt. @ Rs. 1/13/- per cwt. ..	523	13
			Ditto without sand 660 cwt. @ Rs. /1/6/- per cwt. ..	907	8
			Heating and mixing with a quarter of its weight of flux oil Trinidad asphalt 773·6 cwt. @ Rs. 1/6/- per cwt.	851	0
			Total labour ..	5,105	0

VI.—Trinidad Asphalt sealed with Spramex. Socony Mastic sealed with Spramex,—*concld.* (Mr. B. H. Moss.)

Position of work.	Date when laid.	Specification.	Analysis of cost per 100 sq. ft.	Rs.	a.
	Sealing coat completed in Mar. 1927.		*Materials*—		
			25·199 cub. ft. stone @ Rs. 27/- per 100 cub. ft.	6,803	12
			369 cub. ft. sand @ Rs. 10/- per 100 cub. ft. ..	36	14
			618·9 cwt. Trinidad asphalt @ Rs. 11/13/- per cwt. ..	7,310	9
			154·7 cwt. flux oil @Rs. 11/13/- per cwt. ..	1,731	0
			949 cwt. Socony bitumen @ Rs. 7/4/- per cwt...	6,880	13
			Total material..	22,763	0
			Total cost ..	27,868	0
			∴ Rate per 100 sq. ft. = Rs. 26/3/6 = Rs. 2/6/- per sq. yd.		
			The cost of spramexing 104,055 sq. ft. worked out as follows per hundred sq. ft. :—	Rs.	a. p,
			Brushing and cleaning surface	0	8 0
			Mexphalte 0·53 cwt. @ Rs. 7/4/- per cwt. ..	3	13 6
			Heating and spreading mexphalte 0·53 cwt. @ Rs. 1/13 per cwt. ..	0	15 3
			Grit 5⅔ cub. ft. @ Rs. 30/- per 100 cub. ft. ..	1	11 3
			Spreading grit ..	0	1 0
			Consolidating grit 5⅔ cub. ft. @ Rs. 4/- per 100 cub. ft. ..	0	3 8
			Collecting and spreading sand 8⅓ cub. ft. @ Rs. 10/- per 100 cub. ft. ..	0	13 4
				8	2 0
				= Rs. 0/11/9, per sq. yd.	

VII.—Socony Mastic (unsealed). (Mr. A. R. B. Armstrong.)

Position of work.	Date when laid.	Specification.	Analysis of cost per 100 sq. ft.	Rs.	a.	p.
Grand Trunk Road—Mile 112 (12 and 16 ft. wide).	Oct. 1925 to Dec. 1925.	Penetration 1·75 gall. mastic consisting of equal parts by weight of Socony bitumen and Tangri sand on each sq. yd. of 3 in. of metal broken to 2-in. gauge. (Both Chandigarh boulder metal and Delhi quartzite were tried.)	25 cub. ft. Chandigarh ballast @ 17/9 per 100 cub. ft. ..	4	6	3
			1½ cub. ft. sand @ 7/- per 100 cub. ft.	0	2	0
			150 lb. bitumen @ Rs. 10/- per cwt. ..	13	5	3
			Scarifying, sectioning and consolidation ..	2	0	0
			Labour and fuel in heating, mixing and applying mixture ..	2	6	6
				22	6	0
			Additional cost of using Delhi quartzite in place of broken boulders from Chandigarh	2	12	0
				25	2	0

Actual cost per 100 sq. ft. Rs. 22-6-0 and Rs 25-2-0.
„ per sq. yd. Rs. 2-0-3 and Rs. 2-4-3.

VIII.—Trinidad Asphalt (unsealed). (Mr. A. R. B Armstrong.)

				Rs.	a.	p.
Grand Trunk Road—Mile 120 (12 ft. and 16 ft. wide.)	Oct. 1925 to Dec. 1925.	Penetration 1·25 gall. Trinidad asphalt (12½ lb.) with 25% flux oil (3⅛ lb). per sq. yd. of 3 in. of Chandigarh boulder metal in one case and 3 in. Delhi quartzite in another both broken to 2-in. gauge.	25 cub. ft. Chandigarh ballast @ Rs. 17/9/- per 100 cub. ft. ..	4	6	3
			139 lb. bitumen @ 8/- per cwt. ..	9	14	9
			35 lb. flux oil @ 11/- per cwt.	3	7	0
			Labour in scarifying, sectioning and consolidation	2	0	0
			Labour and fuel in heating, mixing and applying ..	2	2	3
				21	14	3

Actual cost per 100 sq. ft. Rs. 21-14-0 and Rs. 24-10-0.
„ per sq. yd. Rs. 1-15-6 and Rs. 2-3-6

IX.—Mexphalte sealed with Spramex. (Mr. L. S. Adlard.)

Position of work.	Date when laid.	Specification.	Analysis of cost per 100 sq. ft.	Rs.	a.	p.
Grand Trunk Road—Mile 121 (1,971 linear feet, 24 ft. wide between brick kerbs).	June to July 1926.	Penetration 1·5 gall. mexphalte with a sealing coat of 0·5 gall. spramex per sq. yd. on 3 in. Delhi quartzite broken to 2½-in gauge.	*Penetration*—			
			25 cub. ft. ballast @ 28/7/- per 100 cub. ft. ..	7	2	0
			6¼ cub. ft. Chandigarh gravel at 16/- per 100 cub. ft.	1	0	0
			16·65 gall. (175 lb.) mexphalte at 8/- per cwt. ..	12	8	0
			Sectioning, spreading and consolidation ..	0	15	0
			Labour and fuel in heating, mixing and applying	1	3	0
				22	12	0
			Sealing Coat—			
			5·6 gall. spramex (59 lb.) at 8/- per cwt. ..	4	3	6
			2⅓ cub. ft. fine grit at 16/- per 100 cub. ft. ..	0	6	0
			Heating and applying spramex ..	0	7	4
			Spreading and rolling gravel ..	0	6	8
				5	7	6
			Total cost per 100 sq. ft. ..	28	3	6
			,, per sq. yd. ..	2	8	3

X.—Socony, sealed. (S. S. Gurbakhsh Singh.)

Position of work.	Date when laid.	Specification.	Analysis of cost per 100 sq. ft.	Rs.	a.	p.
Lahore-Mianwali (Arterial No. 2) Road. 45½ miles —47=1½ miles, 12 feet wide).	Oct. and Nov. 1927.	Penetration 1·7 gall. of Socony bitumen with a sealing coat of 0·3 gall. of the same per sq. yd. over 3 in. Sangla stone broken to 2-in. gauge and covered with an inch of Sangla grit.	25 cub. ft. ballast at 33/- per 100 cub ft. ..	8	4	0
			8·5 cub. ft. grit at 44/- per 100 cub. ft. ..	3	12	0
			2⅓ cwts. Socony bitumen at 7/- per cwt. ..	14	14	0
			Labour and fuel in heating and consolidation ..	3	8	0
			Actual cost per 100 sq. ft. ..	30	6	0
			„ „ per sq. yd. ..	2	11	9

XI.—Mexphalte sealed with Spramex. (S. S. Gurbakhsh Singh.)

Lahore-Mianwali (Arterial No. 2) Road—(Miles 43 to 45½ = 3½ miles, 12) feet wide.	Dec. to Mar. 1927.	Penetration of 1·7 gall. of mexphalte with a sealing coat of 0·4 gall. spramex per sq. yd. of 3 in. Sangla stone broken to 2-in. gauge and covered with an inch of Sangla grit.	25 cub. ft. ballast at 33/- per 100 cub. ft. ..	8	4	0
			8·5 cub. ft. grit at 44/- per 100 cub. ft. ..	3	12	0
			2⅓ cwt. mexphalte and spramex at 7/- per cwt.	16	4	0
			Labour and fuel in heating and consolidation ..	3	8	0
			Actual cost per 100 sq. ft. ..	31	12	0
			„ „ per sq yd. ..	2	13	9

XII.—Mexphalte sealed with Spramex. (Mr. B. S. Shihn.)

Position of work.	Date when laid.	Specification.	Analysis of cost per 100 sq. ft.	Rs.	a.	p.
Lahore-Mianwali (Arterial No. 2) Road (miles 60 to 67¾=8¾ miles 9 feet wide).	Mar. to July and Oct. to Dec. 1927.	Penetration 1·7 gall. of mexphalte with a sealing coat of 0·3 to 0·4 gall. of spramex per sq. yd. of 3 in. Sangla stone broken to 2 in. gauge and covered with an inch of Pathankot gravel. In miles 66 and 67 Jammu crushed stone and gravel were used. This was larger than the Pathankot gravel and required more spramex (up to 0·45 gall. per sq. yd. in cold weather.)	25 cub. ft. Sangla ballast @ 28/- per 100 cub. ft.	7	0	0
			8·5 cub. ft. gravel @ 40/- per 100 ft. ..	3	6	0
			20 gall. mexphalte @ -/12/- gall. ..	15	0	0
			5 gall spramex @ -/12/- per gall.	3	12	0
			Labour and fuel in heating and consolidation ..	3	8	0
			Actual cost per 100 sq. ft. ..	32	10	0
			,, ,, ,, sq. yd. ..	2	15	0

XIII.—Mexphalte sealed with Spramex. (Mr. B. S. Shihn.)

Lahore-Bhakkar (Arterial No. 3) Road. Miles 23-29 (6¼ miles, 12 feet wide).	Nov. 1926 to Mar. 1927.	Penetration 1·7 gall. mexphalte with sealing coat of 0·3 gall. spramex per sq. yd. on 3 in. brick ballast broken to 2-in. gauge and covered with an inch of Pathankot gravel.	25 cub. ft. ballast @ 20/4/- per 100 cub. ft. ..	Rs.	a.	p.
				5	1	0
			8·2 cub. ft. gravel @ 60/- per 100 cub. ft. ..	4	15	3
			19 gall. mexphalte @ 8·4/- cwt. ..	14	15	3
			3·3 gall. spramex @ 8·4/- cwt. ..	2	9	6
			Screening ballast @ -/6/- per 100 cub. ft. ..	0	1	6
			Spreading ballast @ 1/8/- per 100 cub. ft. ..	0	6	0
			Consolidation @ 5/- per 100 cub. ft.	1	4	0
			Screening and stacking ..	0	0	9
			Labour and fuel in heating, applying bitumen and gritting surface, @ 1/14/- per 100 sq. ft. ..	1	14	0
			Actual cost per 100 sq. ft. ..	31	3	3
			,, ,, ,, sq. yd. ..	2	12	0

XIV.—Mexphalte sealed with Spramex. (Mr. B. S. Shihn.)

Position of work.	Date when laid.	Specification.	Analysis of cost per 100 sq. ft.	Rs.	a.	p.
Same Road. Miles 30—38 (9 miles, 12 feet wide).	Apr. 1927 to Sept. 1927	Same specification, except that sand was spread over surface of soling coat and brushed into interstices to prevent bitumen escaping. In miles 37 and 38 gravel from Jammu was used in place of Pathankot gravel.	25 cub. ft. ballast @ 20/4/- per 100 cub. ft.	5	1	0
			3·2 cub. ft. gravel @ 60/- per 100 cub. ft.	4	15	3
			18·87 gall. mexphalte @ 143/-per cwt.	12	10	0
			3·49 gall. spramex @ 168/-per cwt.	2	12	0
			6·8 cub. ft. sand @ 15/-per cwt.	1	0	3
			Labour and fuel in heating, screening, spreading and consolidation	3	10	3
		Actual cost per 100 sq. ft.		30	0	9
		,, ,, ,, sq. yd.		2	11	0

APPENDIX B.

Experiment Lengths of Road Surfacings laid in miles 306 and 309 of the Grand Trunk Road in 1923-5.

Number of section.	Locality. Mile/furlong.	Area.	Treatment.	Remarks. (Jan. 1928.)
		sq.yds.		
1	305/1	694	Tar painting over Pathankot metal in Feb. 1924 and repainted in Aug. 1924.	The traffic over these experimental sections was reckoned as 315 tons per yd. width per day. Mr. G. Gilbert, the officer in charge of the work, reports that with the exception of the bitumen penetration in furlong 308/2 all sections wore very badly and that by Sept. 1926 the surfaces were so bad that they had to be coated with 1½-in. of sand carpet†. This carpet has since broken up in a number of places and has had to be repaired. It is now (Jan. 1928) fairly hard, but wavy throughout, and in the hot weather it becomes soft and spreads on to the berms.
2	,,	525	Tar and bitumen in equal proportions painting over Pathankot metal (Aug. 1924)	
3	305/2	530	Bitumen painting over Pathankot metal in Feb. 1924.	
4	,,	611	Bitumen painting over a coat of crude oil on Pathankot metal (Feb. 1924).	
5	305/3	400	Tar and bitumen in equal proportions painted over cement-grouted Pathankot metal (Sep. 1924).	
6	,,	394	Tar painting over cement-grouted Pathankot metal (Sep. 1924).	
7	,,	346	Jama-brick ballast* grouted with mastic composed of equal parts by weight of sand and bitumen applied at the rate of 1·54 gall. mastic to the sq. yd. (Apl. 1924).	
8	305/4	144	Pathankot metal* grouted with the same mastic as above but applied at the rate of 1·47 gall. to the sq. yd. (Apl. 1924).	
9	,,	109	Ditto mastic applied at the rate of 1·77 gall. to the sq. yd. (Apl. 1924).	
10	,,	388	Ditto mastic applied at the rate of 1·39 gall. to the sq. yd. (Dec. 1924).	

*A 3-in. coat broken to 2-in. gauge.

†The sand carpet consisted of 49 parts by weight of Pathankot sand, 25 parts of ¼" to 1/8" stone chips, 16 parts of Portland cement and 10 parts of bitumen (E. Grade Mexphalte in sections 1—11 and 104 Grade Socony bitumen elsewhere).

Number of section.	Locality. Mile/furlong.	Area.	Treatment.	Remarks. (Jan. 1928.)
		sq. yds.		
11	305/4-5	909	Glutrin and Pathankot metal (Dec. 1923).	This was renewed in Mar. 1926, with water-bound Seraikala stone, tar painted (2 coats) and again painted in May 1927. It is now (Jan. 1928) in very good order.
12	305/5	1311	Glutrin and limestone (Jan. 1924).	
13	308/1	176	Seraikala limestone, water-bound macadam (Mar. 1924).	Resurfaced with water-bound Seraikala stone metal and tar painted in Mar. 1927.
14	308/1-2	293	Nalagarh stone, water-bound macadam (July 1925).	Including the sand carpet has broken up completely.
15	308/2	165	Penetration 1·5 gall. of socony bitumen per sq. yd. of 4½ in. Pathankot quartzite metal broken to 1½ in. gauge, sealed with 0·5 gall. bitumen per sq. yd. and gritted (Mar. 1923).	The original surface is now very wavy,
16	,,	165	Same as section No. 15, but with a second sealing coat of 0·3 gall. bitumen per sq. yd. (Mar. 1923).	
17	,,	43	Same as section No. 15.	
18	,,	267	6-in. plain cement concrete slab (1 : 2 : 4).	The sand carpet slides over the concrete and in places has spread 18 in. across the berm. The thickness is only ¼ in. in places—surface very uneven.
19	,,	178	6-in. reinforced* concrete slab (1 : 2 : 4).	
20	,,	178	6-in. plain cement concrete slab laid in two courses upper 1½-in. (1 : 2 : 2½) lower course (1 : 2 : 5).	
21	308/3	178	3-in. plain cement concrete slab (1 : 2 : 4).	
22	,,	220	2-in. asphalt carpet consisting of 80 parts by weight of Pathankot sand, 10 parts of canal silt and 10 parts of E. Grade Socony bitumen (Dec. 1923).	Surface hard but uneven. The thickness of the carpet varies from ¾ to 2 in. This also has spread on to the berms.
23	,,	..	Water-bound macadam (Apl. 1924).	Renewed Feb. 1927.

*The reinforcement consisted of ½-in. diameter rods, 2 ft. 6 in. apart, 2 in below the surface.

DISCUSSION.

MR. DORMAN, introducing his paper, wished to thank those who had furnished him with particulars of their work and from whose notes he had quoted. The paper was an attempt to show what had been done up to date in providing improved road surfaces in the Punjab to provide for the changing traffic conditions of the Province ; to focus attention on the results obtained from the means tried ; and by offering a comparison of methods and materials, to obtain suggestions for future lines of development.

At the end of 1926 there were 56¾ miles of tar or bitumen treated road surface scattered up and down the Province on the arterial and main roads incharge of the P. W. D., while at the end of 1927 there were 145½ miles. Consequently during the year nearly 90 additional miles had been treated.

The following table contained particulars of the progress made during 1927 :—

Nature of Surface.	Mileage on 1-1-1927.	Mileage on 31-12-1927.
Stone metal bitumen sprayed	9·755	9·965
Stone metal tar sprayed	37·555	47·94
Stone metal tar and bitumen sprayed ..	1·00	1·00
Stone metal bitumen grouted but left unsealed	2·97	37·645
Stone metal bitumen grouted and sealed ..	4·875	16·88
Brick metal bitumen grouted and sealed ..	Nil	23·125
Brick metal bitumen grouted but left unsealed	Nil	4·25
Whole brick, dipped in bitumen, laid as a pavement and surface sealed	Nil	0·25
Sand carpet	0·60	4·50
Total	56·755	145·555

The results tabulated in Appendix B on pages 133-4 explained why the Punjab had almost entirely pinned its faith to bitumen and tar in its efforts to secure a better road surface. Cement concrete had also been tried, but had failed, and it was concluded that it would not stand up to steel tyres. In the United Provinces, however, the Chief Engineer was so satisfied with the behaviour of concrete under heavy bullock cart traffic that he was now laying a strip of ten miles between Benares and Moghal Serai and was contemplating another section between Cawnpur and Unao. This suggested that their rejection of cement concrete had possibly been too hasty.

Again the question arose as to why out of the four bitumen grouting experiments tried in Rawalpindi, Gurdaspur, Jullundur and Ambala, to the same specification, that at Ambala failed, while the other three had been successful. Mr. Macfarlane reported that when dug up it came out in large chunks, and the fact that there was more bitumen found at the bottom than at the top did not suggest that there was any lack of asphalt or of mastic. Soon after the work was finished, however, slight depressions began to form over its entire length and this, combined with the fact that rolling had to be limited in order to avoid crushing the softer Chandigarh and brittle Delhi stone, suggested that perhaps the explanation was to be found in insufficient rolling.

If this was the explanation the question arose whether grouted brick would stand heavy traffic even when protected with a sealing coat of bitumen and stone grit? Unprotected it had only a short life in mile 306 of the Grand Trunk Road, while on the Montgomery—Pakpattan Road it was found it would not stand direct contact with steel tyres. Necessarily it could not be dry rolled to anything like the same extent as stone, and on the Lahore—Moga Road Mr. Freak found he could only pass the roller once backwards and forwards over dry brick ballast. The opinion had been expressed, however, that too much dry rolling was a mistake. Some present could probably say exactly how much rolling was required.

Once more what chance had a sand-asphalt carpet on a weak foundation, such as was being used in the Nili Bar, when it had failed on a much more solid foundation in miles 306 and 309 of the Grand Trunk Road? The thin asphalt carpet could not afford much help in distributing the load, and consequently the whole impact from a wheel might conceivably come on a single brick.

The usual local practice was to provide 6″ of soling coat under a $4\frac{1}{2}$″ wearing coat of water-bound macadam, whereas the home practice was never to have less than a 12″ crust on a clay or yielding subsoil. This suggested that when the traffic called for anything better than $4\frac{1}{2}$″ of metal in the wearing coat, and a 3″ coat of tar or bitumen macadam was substituted, the soling should be strengthened.

Turning to surface painting there was the case of the Lahore Mall which had not been remetalled for the past 12 or 14 years. The traffic—almost entirely motor cars and tongas—on this road opposite the shops averaged about 320 tons per yard width per day and was fairly uniformly

distributed over the whole surface. Some of them might have noticed, however, a very distinct waviness between the junction with Hall Road and the turn down to Sunny View Hotel. This was a length which had been spramexed last year and although at this Congress, a year ago, Mr. Mitchell had referred to the volatility of tar as reducing its life in a hot country below the economic level, this experiment suggested that it would have been better to have stuck to tar on the Mall.

The failure of spramex on the Jail Road appeared, to be, due to the excessive pressure, transmitted by the heavy axle loads, crushing the stone through the bitumen, but instead of the heavy traffic he had imagined when the paper was written, he had since found that the traffic coming into Lahore, along one side of the road, only averaged 108 tons per yard width per day, while that going out, on the other side, was only 64 tons per yard width per day. Loaded bullock carts formed the heaviest item in the incoming traffic and probably their tendency to follow the one rut accentuated the mischief which had occurred. The damage caused by their narrow steel tyres, however, plainly indicated how necessary it was to consider the maximum permissible pressure per square inch of road surface rather than the axle weight.

Another question needing investigation was the most suitable grade of bitumen to use. To a certain extent this depended on the time of year when the work was done, but the problem was to find a bitumen which would neither flow about in the hot weather nor become so brittle as to crack on a cold night. The degree of compactness to which the metal was consolidated also possibly entered into the question. The usual theory was that the aggregate carried the load and therefore each piece of it must be in close contact with the surrounding pieces. The bitumen merely acting as a binder—and therefore the more compact the aggregate the thinner the binder and the less bitumen required. Penetration was normally measured at the temperature of 25° C. (77° F.). At this Congress last year Mr. Pound had recommended a penetration of 35—50 as suitable for the Punjab, while Mr. Mitchell pointed out that bitumen with a penetration up to 70 had been used as well as some with a penetration of only 20—30, but that the latter had developed waviness. The mexphalte generally used had a penetration of 30—40 or 40—50 and spramex 80—100. Trinadad refined asphalt (T. R. A.) had a penetration of 45—50, which was increased by the addition of flux oil before use. The Socony (Grade 104) used at Rawalpindi and elsewhere had a penetration of 60—70. The Barber Asphalt Company had gone into the matter some years ago and had advised that it should not be necessary to use in the Punjab climate anything harder than bitumen having a penetration of 75.

This all suggested that road building in the Province required much closer study than it had hitherto received. The aid of the physicist and chemist would probably have to be sought. Experimental work would have to be continued on a more scientific basis, than heretofore, the costs of construction and maintenance would have to be more accurately recorded, wear and traffic more closely observed and the results co[illegible] and analysed.

They must endeavour to avoid costly failures such as was recently reported to have occurred on the London—Southend Road. This 24' wide carriage-way, consisting of 3" of asphalt over 12" of hard core on 6" of clinker had been constructed at a cost of £ 1,200,000 and opened by Prince Henry less than three years ago. It had been disintegrated by the action of the London Clay and had now to be reconstructed at a further cost of £ 300,000.

As the Chief of the United States Bureau of Public Roads said the other day "We pay for good roads whether we have them or not and it is cheaper to build them than to go without them."

MR. MACFARLANE attributed the failure of the experiment tried on mile 120 of the Grand Trunk Road to mixing sand with the bitumen. In the work done in mile 121, in 1926, no sand was used at all but only the bitumen by itself and it was a complete success. He thought that it was quite likely that the mixing of sand with destbitumen royed the binding quality. Another point was the absence of proper arrangements for mixing as, by the time the mixture was applied to the road, its temperature must have been considerably lowered by the sand. He thought that Mr. Adlard would agree with this.

On page 112 of his paper Mr. Dorman had mentioned that opinions were divided as to whether the sealing coat should be laid immediately after the grouting was completed or not. In mile 120 he had tried puting on a sealing coat of spramex on the old penetrated road but it had proved a complete failure, as it came away in big patches. He had discussed the point with a representative of the Asiatic Petroleum Company who said "get on with your sealing coat as quickly as you can immediately after you have done your penetration."

MR. ADLARD agreed with Mr. MacFarlane's remarks about bitumen but wished to emphasise that, pending the experiments with bituminous surfaces which had not been any too successful up to the present, the roads should not be allowed to fall into disrepair, as appeared to have happened to some miles of the Amritsar—Lahore Road. Temporarily to put a passable surface on this type of road he had found it quite successful to scarify the whole mile, trim the surface up to camber, and consolidate it. He had had the same condition in Ambala towards the end of his division. In January 1927 there were three or four miles for which they could not get stone, and while they had to scarify and roll. This had turned just as good as a new coat. He worked out that they had saved by that type of work during 1928-29, about Rs. 80,000 against collecting new stone, and that was only allowing the difference in the life of new stone against the life of scarified stone, which roughly amounted to five years against two years. If they allowed two years' life on the stone they were saving Rs. 2,400 per mile. The average immediate saving per mile of scarifying was Rs. 6,000.

Further in places where there were heavy ruts, scarfying was considered to be more suitable and economical than waiting for the collection of a new coat. He recommended a wearing coat should be scarified

and re-rolled. Half a furlong could be done in a day with one engine. It would give the public a road in a fairly good condition to tide over immdeiate difficulties.

BAWA BUDH SINGH considered the paper to possess more than one novel feature ;

(i) Papers were generally presented to the Congress to trumpet their successes, but this was to parade mostly their failures.

(ii) The paper was the compilation of other Engineers experiments.

(iii) It was of an academic interest only, because the Government had probably given up the idea of building any more bituminous roads.

In his opinion, the failure in the case of all these experiments with bitumen, spramex, etc., was neither due to the climatic effect of the Punjab nor to the lack of proper supervision. The design of their roads was wrong. The real difficulty lay in their foundations being too weak to bear as much traffic as 400 to 500 tons per yard per day, and therefore, called for more substantial foundations. The bullock cart pounded the road with highly concentrated loads, while a motor lorry tore up and ground the surface. The shock was transmitted to the soling, which, if weak, gave way and the surfacing collapsed. It was wrong to suppose that a sealing coat could act as a shock absorber or that the thickness of the soling was of no consequence. In Bombay and Karachi the foundations are of cement and reinforced concrete. Another cause lay in heating their mastic to a high temperature while the aggregate was comparatively cold, with the result, that the heated mastic lost a good deal of its heat when it came in contact with the aggregate and failed to make a compact mass. Instead of covering the stones with a thin coat, the mastic either remained in thick plastic scales, or settled down at the bottom. Both the aggregate and mastic should be heated together, laid hot and rolled down, but this would need expensive plant. Personally he was not against the use of bitumen roads, where they were actually needed, but with only a 6" or 4½" soling coat he considered them waste of money.

Any fear of the exhaustion of their stone quarries, was merely a false alarm. They had heard all these years, the great scientists declare that the sun would lose all its heat and energy in years to come, as such a colossal amount of heat was being lost every second, but these scientists measured time by units approaching infinity. The mountains of the Punjab would not fail them. The real difficulty was in the length of cartage, and this trouble increased as their roads got farther away from the railway line. The situation could be eased, if the canals were made navigable as in the United Provinces.

Another way of overcoming the expensiveness of the stone, was to make experiments with bricks and clinker. There should be no difficulty in developing a brick of the required hardness and toughness if they proceeded in a scientific way ; and this would also reduce the cost of cartage. The possibility of cement roads had also been left out of consideration. There were great possibilities for these roads if properly

made. As they could burn hard bricks locally, let them metal their roads with that material in the first instance, and when the traffic increased sufficiently they could give a more durable surfacing.

RAI SAHIB LALA SANT RAM referring to the Gurdaspur Experiment mentioned on page 108 where it was stated that the road was shewing signs of disintegration under the bullock cart traffic from the railway station, but the fact was that the road developed ruts within three months of its completion under the heavy bullock cart traffic carrying stone metal from the railway station to a district board road. After this traffic ceased the rutting did not increase. The cracks that had appeared on the ridges closed off themselves and disappeared after sometime. For two years the road did not require any repairs but it was now showing signs that it required patching, and a sealing coat had become necessary.

Regarding the method of laying mentioned on page 111 he wondered whether a 10-ton tandem was used or a 6-ton? He had found that the 6-ton tandems were not of much use, except for rolling a sand carpet or a sealing coat. He would like to know the experience of other officers using tandem rollers (10-ton or 6-ton) whether they were any good for consolidation work. His experience was that a 6-ton tandem roller was of little use for consolidating roads. As regards the sealing coat mentioned on page 112 what was the object of allowing three or four months to elapse before sealing the surface? A sealing coat should be laid immediately after the penetration. As regards a sand carpet nothing less than a 2" carpet was of much use. The 1" carpet laid on the experimental length, in mile 306 of the Grand Trunk Road, soon became patchy and had already disappeared in places. He did not think that the failure of the surface coat on Jail Road was due to insufficiency of foundation. Inadequate foundation might cause waviness but could not produce disintegration of the surface, which in his opinion resulted from the direct action of the wheels of heavily loaded carts on the surface covering and through it on to top the wearing coat. It had been suggested that the narrow wheels of bullock carts had abraded the stone through the surface coat of spramex, but he could not agree with this, because spramex was a soft material, and until it was pierced through, it could not transmit the abrading action to the stone below. He was of the opinion that it was on account of the grit of the Pathankot stone, being harder than the Sarai—Kala stone underneath that the latter was crushed. Road corrugation was not so much due to a bad foundation or bad consolidation, as to the nature of the binding material. Bitumen being a soft and plastic material reduced the friction between the pieces of stone and destroyed their keying or wedging action, so that when bitumen became softened in the hot weather the grouted road crust went into ridges and hollows under the rolling action of the heavy traffic, which was more pronounced on the side of the road carrying the loaded carts downhill, at a greater speed than uphill.

As regards dry rolling, if it was carried beyond a certain stage, the pieces of stone became round and lost their keying or wedging quality. Too much dry rolling before bitumen penetration was thus harmful.

In connection with the road between Lahore and Amritsar, Mr. Adlard had suggested that the wearing coat should be scarified and rerolled so as to give a good surface to the traffic, without renewing the wearing coat. That could only be done, where there was something of the wearing coat left. Even where there was something left and only rutting had occurred, there was not more than an inch of thickness of metal, and it would not be of much use scarifying or consolidating it without the addition of new metal, as it would not last even for a month. In many miles, the wearing coat had entirely disappeared by having been ground down to fine powder and thrown on to the berms. What they were proposing therefore in this case, was to renew the bad miles as soon as possible, widening the road at the same time to 20 feet, and covering it with tar.

MR. STUBBS began by answering two of the questions already raised in the course of discussion. The reason why he did not apply a sealing coat immediately after the grouting was to economise in bitumen, as experience in the Nili Bar showed that by delaying the application of the sealing coat for three or four months there was a saving in bitumen of about twenty per cent. Moreover the delayed application did not affect the adhesion of the sealing coat.

Regarding the weight of the roller he had used a 10-ton tandem roller, because a 6-ton tandem roller was far too light. His main trouble was with the vertical boiler. The tubes were spaced only $\frac{3}{8}$" apart and this made cleaning difficult. Silt collected on the bottom and caused burning of the bottom plate. Experience showed that a 10-ton tandem did not crush brick metal.

He agreed with Bawa Budh Singh that the foundation of the road was a very important factor. Roads in Europe had eight to twelve inches of reinforced concrete foundation and it was presumed that there was reason for laying such a heavy foundation. In the roads in the Nili Bar $4\frac{1}{2}$" brick soling was used and this was inadequate. There should be at least $7\frac{1}{2}$".

Corrugation was caused through movement of the surface, this was minimised by thoroughly compacting the surface, which was achieved by pre-rolling as much as possible and filling up holes in the surface, due to imperfect spreading, by adding more metal before pouring any bitumen.

Another important point was the extent to which motor traffic was increasing. Three years ago there were 200 motor buses using our roads, this year there were about 800 and in another three or four years the number would probably be about four times this figure. It was, therefore, necessary that the roads should now be constructed to cope with this anticipated increase in traffic.

Regarding brick ballast, he thought there was no difficulty, if really well burnt brick metal were used, it was a mistake to break brick metal too small. He thought that the cause of the failure at Ambala unquestionably was due to the mixing of sand with bitumen and the main

reason why the mixture of sand was a failure was due to inadequate pre-rolling. If adequate pre-rolling had been done the mastic would not have penetrated to the bottom.

Regarding the widening of the Amritsar road and then tarring it, he thought that although it was not his business to criticise it would be necessary to relay the whole road in another three years if this specification were adopted.

MR. NASH considered the reason for rutting and waving, was largely due to an excess use of asphalt. He understood that Mr. Macfarlane, in digging up portions of the road at Ambala, which had rutted and waved, had found pools of asphalt at the bottom and signs of movement under traffic. The function of asphalt was to bind the aggregate together and an excess of asphalt only tended to lubricate the metal. He agreed with Mr. Stubbs regarding foundations. If the foundations were not strong enough to carry the traffic the whole road would go to pieces regardless of the material used in the wearing coat. It was advisable to allow any excess asphalt to work up under traffic before putting the seal coat on. As regards penetration, or degree of softness of the asphalt cement used, it had been found, from experience, that a penetration of 75 was most suitable for hand-grouted work, 25 for machine mixed work, and as much as 200 for surface painting. The painting on the New Delhi Roads was being done with 40 parts of fluxing oil to 100 parts of Trinidad asphalt, which gave a penetration of over 200. Some of that work would be down three years next May and was still in good condition.

MR. VESUGAR said that he had looked carefully through Mr. Dorman's paper to find out whether he was "pro" bitumen or "con," but found that the paper dealt with no more than the title indicated, *viz.*, "the construction" of bituminous roads. It was like somebody explaining a new method of wall construction and confining himself to merely describing the bond without discussing its relative merits.

He thought he was voicing the opinion of most members when he said that an opinion and criticism was looked forward to from the author, and asked the members indulgence in being allowed to repeat briefly the various works mentioned in the paper with their results.

These were :—

(1) A short length of brick ballast in mile 306 of the Grand Trunk Road left unsealed—failed in 18 months.

(2) A short length of sand carpet in mile 309, very pronounced waves.

(3) Sand carpet on the Pakpattan—Montgomery Road—Condition not stated.

(4) Surface treatment with spramex at Rawalpindi, broken up in two years.

(5) Miles 1, 2 and 4 of the Murree road—surface treated with mixture of tar and bitumen.

Mile 1 had to be remade in 1926 and was not expected to last another year. Failure.

(6) Miles 2 and 4 had to be remetalled in 1926. Again treated with spramex and again showing signs of breaking up. Failure.

(7) Mile 3 of Murree Road. Grouted with bitumen.

(8) Mile 44 of the Amritsar Baijnath Road near Gurdaspur. Has stood so far, but is now showing signs of disintegration.

(9) Small bit of road at Jullundur, all right at present, but not expected to last. Moderately successful.

(10) A mile at Ambala, put in under favourable conditions and with great hopes. Had to be renewed after two years.

(11) Near the same place, widening of road where one would think conditions would not be as good as in the previous case. Quite successful.

(12) Pindi Bhattian, 14 miles laid. No remark made about its present condition. Traffic very light.

(13) Beyond Sharakpur, several miles of grouted brick metal. No remarks about present condition. Traffic light.

(14) Harike Road, 12 miles with brick metal. No remarks about present condition. Traffic light.

(15) Nili Bar, 49 miles grouted. Work just finished. Traffic very light.

(16) Asphalte carpet at Fitna, 5 miles laid by a very large firm of contractors. Failure.

(17) Spramex surface treatment near Lahore on Jail Road. Failure.

(18) McLeod Road near railway station, spramexed after having been treated for several years with tar. Tarred surface stood all right. New surface not expected to last through another hot weather.

(19) Surface treatment on Ravi Road edges. Failure.

(20) Ravi Bridge approaches. Very marked waviness.

It would be seen from this list that, out of about twenty separate works reported, twelve had been found to be a failure, three had turned out a definite success ; and of the remaining five, either the fate was not known or not mentioned in the paper. This was giving everyone furiously to think. About 150 miles of bitumen roads had already been constructed in the Punjab. At a conservative estimate this represented a cost of 20 lakhs. He considered it about time that a halt was called,

the conflicting results obtained, considered, and the miles already laid given the only try out that matters, that of age. The justification for the use of bitumen had to be considered from two aspects :—

(*a*) to provide a long lived surface on an existing important road to withstand heavy traffic which broke up a cheaper type of construction.

(*b*) to provide a road with long life in the first instance in places where stone metal for maintenance was only obtainable at a very high cost, owing to various causes. With the limited funds at their disposal, these were the only two conditions in which bitumen could be called essential. If bitumen was the solution to either of these two problems, not to use it would be to waste public funds.

It was the duty of the engineer to advise the Government on this matter, but his advice must have behind it the authority of experience and mature consideration. He was of opinion that the time had come when Government should appoint a committee of say five engineers who would consider the work already done dispassionately, interview the officers and other staff who had carried out the work and who had had to do subsequent maintenance at the site of the work and get out clear conclusions and recommendations both as regards specifications and occasions when bitumen could be used. This committee must consider the engineering as well as other aspects involved and report when this type of construction should be employed, and to what specifications constructed.

He regretted that he could not put forward any more constructive suggestion. At present there existed a dense fog of figures as regards the experiments carried out, clouding the useful information derived until such information was carefully, systematically and patiently sorted out and considered.

The tendency in the work done was to try to run before one could walk. There was too much "research" by individual officers, and no benefiting from other workers' experience. Instead of putting down miles of unsatisfactory bitumen roads by trying to work to a price, they ought to begin with the same specification for the entire structure of the road as was followed in places where bitumen had been a success and gradually cut the specification till they came to the irreducible minimum. The groping after short cuts by haphazard experimenting had led nowhere.

The committee inquiring into the subject must give full attention to all aspects of construction when bitumen was to be employed. Correct consolidation and ageing of the earth bank, and a satisfactory foundation were of as much importance to the life of a wearing coat as the materials employed for the coat itself. As regards loads imposed by bullock carts, he reminded members that whilst the fact of these loads being concentrated by narrow tyre widths was always emphasised, it was forgotten that, the want of any cushioning or springing was even more ruinous to a

road. He ventured to state that it would probably pay Government to make a present of suitable wheels to all owners of carts. At the same time Government would be doing a humanitarian action by giving suitable axle bearings also. These bearings were quite cheap and their provision would be of greater benefit to the bullock than a veterinary hospital. He did not suggest that government should throw in springs and rubber tyres also, but in considering the composition of the wearing coat the fact should be remembered. It was possible that some sort of carpet construction would be more resilient than metal, and a form of construction which would do away with surface imperfections would also do away with the need for springs.

MR. FREAK stated that with regard to the use of brick ballast as a substitute for stone metal, it should be made clear that brick ballast was an inferior substitute and should only be used whenever it was not possible to use stone. Stone was generally impossible during the construction of a new road, distant from a Railway station, due to the difficulties in obtaining sufficient transport for the expeditious collection for long leads, over unmetalled roads. Once the new road had been metalled, future remetalling could probably be done with stone, as transport by Foden wagon or motor lorry could easily be done. The strength of brick ballast was insufficient without bitumen grout and a stone *kajri* sealing coat. The wearing capacity of such a road was that of the sealing coat, as the ballast was not hard enough to stand wear, so that the sealing coat should be renewed as soon as it was worn through. For this same reason the sealing of grouted brick ballast had to be done at once.

On the Lahore—Moga road, it was stated that the dry brick ballast was lightly rolled with a 10-ton roller. This was due to the roller crushing the brick ballast if it were rolled more than once back and forth, but once the bitumen grout had been poured in, the roller no longer crushed the ballast and so it was possible to thoroughly consolidate the grouted ballast. The grout was poured in strips diagonal to the road, so that any fat places due to slight overlapping of the strips should not be so likely to form cross waves or longitudinal ruts in the road.

It had been found that the quantity of bitumen required for the sealing coat was dependent on the quality of the grouted ballast; the smoother the surface of the grouted ballast, the less the bitumen required for the sealing coat and *vice versa*.

As stated in the paper it was premature to report finally on the tar pitch experiments, but it could be stated that while grouting with tar pitch mixtures, in the proportions of 1 : 3 and 1 : 2, tar to pitch, by weight, had been successful in Calcutta, Cawnpore and elsewhere, here, in the Punjab, it had been found that such mixtures were too brittle in the winter, and it was necessary to use a 1 : 1 mixture for the grout and a 1 : $\frac{1}{2}$ mixture for the sealing to stand the cold of the Punjab winter nights, particularly for the sealing which had to stand as much as ten degrees of frost on the surface. It remained to be seen whether these mixtures would not be too fluid in the hot weather. With regard to the

various kinds of grit, it was doubtful whether round water worn pebbles, such as Pathankote *bajri*, were as suitable as sharp chips ; the pebbles were so hard that they were not crushed by a 10-ton roller. It was not suggested that chips of a softer stone, such as limestone, should be used, but it might be advantageous to break up quartzite pebbles into chips.

MR. CAMPBELL said that he had seen a certain amount of water bound maccadam work in England. There they laid by hand a foundation of stone which was more or less cubical in shape. It was laid and packed by hand. On the top of that they rolled in about 4" thickness of broken grit. They tried to use pebbles of the same type as the Pathankot gravel, but found that they did not answer the purpose. They had two sorts of binder available one was the fines from crushers and the other was rotten disintegrated granite, which was found in certain parts of the country and was brownish in colour. He had noticed in this country that in the majority of the roads once a year they used an earth coat. He wanted to know why a coating of earth was put on, because he considered it to be absolutely useless. There was also the question of holes in the road. In England the great thing was to compete against rain water, which generally penetrated right into the ground. If a small hole was allowed to develop in the surface of the road, then a succession of them would begin to appear right down the road due to the bumping of the wheels into and out of successive holes. Road gangs should be instructed to keep a strict watch over this, and made to pick out the ballast all round a hole, fill, tamp and blind it thoroughly as this was the only possible way of stopping the formation of further holes.

MR. DHODY thought the consolidation of ruts worth trying, and to better resist rutting, suggested the provision of reinforced strips along the surface just where the wheel tracks might be expected.

MR. DORMAN, replying to the discussion, pointed out that Mr. Macfarlane's explanation of the failure of mile 120 would only apply to the lengths in which socony mastic had been used, whereas the lengths laid with Trinidad asphalt, to which no sand had been added, had failed in the same way. Consequently it was necessary to find a reason equally applicable to both. Moreover, the socony mastic laid to the same specification in Gurdaspur and near Rawalpindi had worn well. He hoped that Mr. Macfarlane and Mr. Adlard would try to get to the bottom of the matter, as it was most important to find out the real reason of the failure in order that others might benefit by the experience. The fact that the sealing coat applied to the surface of mile 120 had come off in patches was probably due to a film of dust having been left on the grouted surface. The application of the sealing coat was often postponed to allow the grouting to be worked in by traffic, so that any surface inequalities which developed in the process could be made good when sealing.

He was afraid that Mr. Adlard's system of scarifying and rerolling would not, as pointed out by Rai Sahib Lala Sant Ram, stand up to the heavy mixed traffic on the road between Lahore and Amritsar sufficiently long to make it worth trying.