The Author. but the wise man learnt from the experience of others, and the Author ventured to submit the results of his own work, in the hope that the information given might be of use to his brother engineers.

Correspondence.

Mr. Boulnois. Mr. H. Percy Boulnois remarked that, although the Author gave some interesting particulars of the tonnage of traffic on the roads in Sheffield, he did not reduce them to the necessary unit of tons per yard width between curbs per annum, which was the only basis of proper comparison. With regard to the widths of carriageways, although the Author might find that 24 feet was sufficient in Sheffield, where probably the majority of the traffic was slow, such a width for a fast, or mixed traffic, was inadequate, and 30 feet was required. The former multiple of 8 feet per vehicle was ample for horse-drawn traffic, but with the vastly increased speed of modern traffic a multiple of 10 feet was necessary. The Author was very sound in his views on the absolute necessity for the proper drainage of roads; water was almost as great an enemy to roads as traffic. He was equally right with regard to the support of the haunches of carriageways by curbs, or other means; without this support the upper crust had a tendency to spread. There were well-known cases of this having occurred, with waterbound macadam roads, where the metal had been found pushed under the verges to a distance of 18 inches and even more. The Author appeared to be an advocate of heavy rollers for bituminous materials, which seemed to be somewhat at variance with modern opinion, as heavy rollers were held to be among the causes responsible for the inception of waves—one of the bugbears of modern road-construction. He did not say whether the roads under his charge suffered at all from this detriment. The Author's recommendations as to camber should be studied by all road-makers; he was perfectly right as to the cause of most accidents from slipping of horses or side-slip of motor-cars being due to excessive camber, and it was evident that the immunity from such accidents in Sheffield was due to his wise diminution of the gradient of camber. He did not appear to have been very successful with concrete roads, which might have been due to a variety of causes. There was no more difficult road to construct than an unsurfaced concrete carriageway. Concrete was rather a "tricky" material to deal with; each batch must be absolutely similar in composition, the cement and aggregate carefully selected and kept uniform, and the quantity of water reduced to a minimum and varied in accordance with weather conditions; and

many other precautions too numerous to mention must be taken. There had been many failures with this method of road-construction, which rendered it somewhat unpopular, although a properly-made unsurfaced concrete carriageway should prove to be ideal for modern rubber-tired traffic. The Paper came at an opportune time, as the question of roads had now emerged from a communal to a national question. Mr. Boulnois.

Mr. Osmond Cattlin agreed with the Author on many points raised in the Paper, particularly that the basis of road-making methods must be the volume and character of traffic which the roads had to carry; but ways and means formed an influence, and, further, it was not possible to discard as uneconomical those pavings and foundations which successfully maintained the very heaviest traffic. There was a vast difference between continual heavy and occasional heavy traffic; and, if an engineer refrained from putting down a certain class of paving on a roadway because the traffic-weight exceeded 80 tons per yard width per hour, Mr. Cattlin contended that such paving must be considered a second-class paving. Second-class pavings existing on a road with more than 80 tons per yard width per hour were expensive with regard to maintenance, and therefore uneconomical. He had adopted the weight-per-yard-width-per-hour method of estimating traffic, as the width of the carriageway was such an important factor. On roads with a traffic as low as 5,000 tons per day, any second-class paving could be successfully maintained at a small cost, and he did not regard a life of 11 years for tarred macadam under such conditions as anything remarkable. He knew of many tar-macadam roads, certainly 10 years old, with that weight of traffic, still in excellent condition; but they were cross roads and not main roads. Confusion arose among laymen through the publication of successes obtained with certain classes of paving without a statement of the actual conditions of the road in which they were laid. Mr. Cattlin.

The two types of traffic to-day which wore road-surfaces quickly could be classed as "heavy" and "fast." The former consisted of a volume of miscellaneous traffic, covering the whole of the roadway all the working-hours of the day. "Fast" traffic was what the county main roads had to bear. Undoubtedly heavy traffic could be most economically provided for by means of a first-class paving and foundation, which, he submitted, meant a concrete foundation at least 9 inches in depth. There were only three classes of surface at present suitable for "heavy" traffic, namely, in order of economy, granite setts, creosoted wood blocks, and asphalt. First cost often prevented the adoption of such pavings; but, taking the life into consideration, the greater the first cost, the cheaper was the

Mr. Cattlin. road in the end. It was waste of money to put down wood blocks for light or intermittent traffic, as the wood rotted away; and, further, it was false economy to put down any of the pavings mentioned above on a defective concrete foundation. Many old concrete foundations in London to-day, 6 inches in thickness originally, with wood blocks laid upon the surface, were hopelessly pulverized by the heavy motor-omnibus traffic. The same thing had happened years ago in Central London with compressed rock-asphalt on concrete foundations 6 inches in thickness, necessitating entire reconstruction of the road. No paving which had not an adequate foundation would sustain the weight of heavy traffic, either slow or fast.

With regard to the surfacing of a concrete foundation of adequate strength, he had relied for many years on the valuable information given in a Paper[1] by Mr. H. R. A. Mallock, F.R.S., who had shown that, for the perfect road, the surface paving should be sufficiently elastic to absorb the shock of traffic put upon it; but the only approach to that ideal at present was the creosoted deal-block. Rubber paving was as yet too costly to be adopted and of uncertain success. The Author was unjust to creosoted deal-block paving, in regard to the quoted price of £1 per superficial yard. The last contract let by the Lambeth Borough Council for 8,270 superficial yards of 3-inch by 8-inch by 4½-inch creosoted deal blocks, laid and grouted complete, on a concrete foundation prepared by direct labour, was 12*s.* 4*d.* per superficial yard, which included 3 years free maintenance. Creosoted deal-block paving was economical to maintain, and only granite setts were superior in that respect. Several stretches of creosoted deal-block paving on main roads subject to heavy traffic in Lambeth had been laid more than 12 years, and the average cost of maintenance during the last 2 years had been 5*d.* per superficial yard per annum. Aberdeen granite setts on a concrete foundation of proper depth were more economical, but were too noisy for residential and shopping thoroughfares. With regard to "fast" traffic, such as was borne by the county roads, he appreciated fully the fact that an impervious paving without a liability to rot was essential for several reasons. Small first cost was important, and, provided there was a thoroughly firm foundation of old road, a carpet coat of granited asphalt was the most economical. Where the foundation was doubtful, two-coat work was necessary. Both those pavements were affected by the summer heat, and became wavy and corrugated in consequence. He had noticed also some sheet-asphalt work in county main roads which was entirely broken up on the haunches on account of lack

[1] Minutes of Proceedings Inst. C.E., vol. clxxviii, p. 111.

of foundation. This class of work was of no use unless there was a thoroughly good road core. The present interest should be in the direction of unsurfaced concrete for county main roads, and, providing the cracking trouble could be overcome, this should prove successful. Whilst unsurfaced concrete was not suitable for "heavy" traffic in towns, and therefore at present could be ranked as a second-class paving, it would appear to be well worthy of trial on roads with only a small volume of heavy traffic. The value of this class of paving was plainly shown on the new Surrey arterial roads. With regard to slipperiness of asphalt surfaces, it was necessary, in the case of compressed powder and sheet asphalt, composed of bitumen and sand, to provide means of gritting the surface during periods of weather when the atmosphere was humid. Also, frequent washing of the paving was an essential feature of the care of this class of road. He had advocated for some time past the stone-filled carpet coat for asphalt work, either single or double coat; that provided much safer travelling, but was not free from risk if motor-vehicles were driven at excessive speed when the surface was wet and muddy. Mr. Cattlin.

Mr. R. DRUMMOND observed that the Author went very fully into the question of modern practice in road-making, and had prepared an excellent Paper on the subject; but he felt sometimes that evidence from a purely town experience was not so helpful as it might be for the maintenance of county roads. At one time heavy traffic was wholly a town consideration. The position was now changed: the county roads had to carry heavy loads at considerable speeds, and the two combined formed the great damaging agency. Heavy loads in a town had to move slowly, because of the density of its traffic; in the country there was no such safeguard, with the result that a problem had arisen in connection with county roads which engineers in towns were not called upon to consider. It was usual to compare roads by reference to the tonnage passing over them, and thereby to determine the composition of the surface required to carry the traffic; but it was also essential to take into account the speed of the traffic as well as the weight. Speed, moreover, was also a factor in determining the necessary width of roadway. The Author pointed out that numerous small units had been replaced by a smaller number of larger and swifter ones, all of which increased the carrying-capacity of the road; and in this way congestion had been prevented, so that a roadway 24 feet in width might quite easily carry 4,000 to 5,000 tons a day without inconvenience. It might be well to aspire to a 30-foot width, but Mr. Drummond considered that that was the limit to which a macadamized surface could be laid economically, with regard Mr. Drummond.

Mr. Drummond. to both camber and a stable foundation. The Author remarked that a concrete foundation was the ideal, and such an opinion was generally accepted; but, except in some extreme case, cheaper methods must prevail so far as county roads were concerned. He agreed with the Author regarding the use of the old road-crust as a foundation; from personal experience he found that there was none better, and when it was strengthened by introducing two lines of 6-inch by 4-inch dressed setts along the centre of the carriageway about 10 or 12 feet apart, together with side curbs, this form of foundation was cheap, simple to lay, and very effective; and even in a new formation such as was shown in *Fig.* 2 (p. 27), two lines of setts could profitably be used. The lines of setts checked lateral movement and largely stopped waviness and corrugation. For new foundation work it had hitherto been usual to specify 10-inch hand-set bottoming, which took a long time to settle and rendered the surface unstable; whereas a better plan was to lay two 5-inch layers, each layer steam-rolled and properly supported at the haunches. He agreed with the Author that bituminous macadam and asphalt would be the principal road-surfacing materials in this country for many a day, but, as to the method of laying and consolidating the materials, he must part company when the Author emphasized the need of so much heavy rolling. It was not an infrequent occurrence to find a newly-laid bituminously-bound macadam road showing considerable waviness before it received any traffic at all. This he attributed to careless workmanship, over-rolling, or both; and he might also add, to the voids in the first coat not being properly filled. It was a pleasure to note from the Paper that road-engineers were now using bituminous macadam instead of tar macadam; and the Author gave valuable information as to his method of application. For more than 8 years Mr. Drummond had been grouting with bitumen fluxed with tar, in the proportion of 3 of bitumen to 1 of tar in summer and 2 to 1 in winter, with excellent results. There was now no question as to the thorough economy and durability of asphaltic surfaces, and it was gratifying to have evidence and proof of their utility from such an experienced engineer as the Author. With regard to comparative costs, statistics in different parts of the country might vary as to actual figures, but the figures given might be taken as a general average, both as to cost and life of the materials mentioned. The Paper was helpful and instructive, and much good would accrue from its dissemination. Every one would appreciate the trouble and care the Author had taken in compiling it.

Mr. Mager. Mr. F. W. MAGER considered that the Paper was a timely contribution to the important subject of road-construction. He was

Mr. Mager.

responsible, as State Engineer, to the Government of Perak (Federated Malay States) for the maintenance of 900 miles of metalled urban and country main roads, involving an annual expenditure of $1,500,000; and he had lately been engaged in investigating, in England, recent advances in road-engineering practice, in which he had received the invaluable assistance of the officers of the Roads Department of the Ministry of Transport. He had submitted his conclusions in a detailed report to the Government of Perak, and was now deeply interested to find, in the Author's Paper, a contribution covering, *mutatis mutandis*, the same ground. Mr. Mager held that the essence of road-administration must be road-classification, and that such classification must be based on a properly-conducted census. It appeared to be important, if difficulties were to be avoided when attempting to draw comparisons between different administrative areas, that the standard unit of traffic should be " tons per unit of time per unit of width of road." Returns sometimes gave " tons per unit of time " only, omitting " unit of width." The present distribution of traffic in the State of Perak was :—

Up to 5,000	tons per	month	on	30	per cent.	of the road mileage
5,000 to 10,000	,,	,,	,,	30	,,	,, ,,
10,000 ,, 20,000	,,	,,	,,	27	,,	,, ,,
20,000 ,, 60,000	,,	,,	,,	10	,,	,, ,,
Exceeding 60,000	,,	,,	,,	3	,,	,, ,,

The maximum recorded intensity was 210,000 tons per month on a 24-foot roadway; reduced to a unit of width, that gave a traffic intensity of about 50 per cent. of that dealt with in the last British traffic-census report. While passenger-traffic was almost entirely by motor, the two-wheeled bullock cart still carried the major part of the road-borne goods-traffic, but it was being steadily superseded, not only in towns but also in up-country districts, by motor-lorries.

Road construction began, in Perak, about 1880; and the State was indebted to Mr. F. St. George Caulfeild, M. Inst. C.E., its first State Engineer, for the excellent location and construction of the earliest roads. A ruling gradient of 1 in 30 was laid down and had rarely been departed from since. A width of 12 feet was then considered an ample metalled track for the bullock carts and horse-drawn gharries of those days, but it was sufficient no longer. An extensive improvement programme was in hand, but the standard width still appeared to be open to discussion. He gathered that 20 feet was regarded as the standard minimum width for ordinary county main roads in England, and 30 feet for arterial roads communicating with the London area; this seemed also to be French practice; but the Author appeared to advocate 24 feet, and

Mr. Mager. Mr. Mager would be grateful if he would deal further with this essential point in his reply.

With regard to crusts, standard construction in Perak was formerly 4 inches of hand-packed "block" metal, topped with 3 inches of broken ballast, all rolled and consolidated. This light crust had stood surprisingly well even under fast motor traffic; there had been, especially, a freedom from surface corrugation after surface tarring. He ascribed this largely to the care taken with subsequent remetalling; surfaces were always scarified, small material was screened out for subsequent use as topping, the new stone was hand-packed, each individual stone being carefully placed like a piece in a mosaic, rolled in clean, and then blinded with clean material. A flat camber had always been the rule, and attention had been given to maintaining and strengthening the water-tables. Deformation had certainly taken place at points, but not to the serious extent witnessed sometimes under similar conditions in England. Even 8,750 tons per month per foot of road was carried fairly well on a tar-dressed crust of small stone built up to about 12 inches in thickness by successive remetalling operations. That costly special foundations were not necessary always, even in England, would appear from his observation of the Bath Road near Slough; 8,500 tons per foot per month were there being successfully carried on an old road-bed of about 12 inches of macadam, topped with asphaltic concrete; and he was glad to observe that the Author advocated the retention of old road crusts and, not less, the use of available local materials, as against such heroic but, alas, unattainable measures as the provision of brand-new concrete foundations. Tar painting had, in the State of Perak, been largely adopted as, at least, a palliative on waterbound macadam. Results, both from a financial and from a motorist's point of view, were excellent. The same could not altogether be asserted of residual bitumen as a surface dressing, and he noted that the Paper confirmed this. Mr. Mager would suggest more investigation of the wearing qualities of low-grade stone as an aggregate for tar macadam. Iron slag formed a poor waterbound macadam, but had proved an excellent aggregate with tar; there seemed no reason to doubt that equally good results would be obtainable with rocks of such wide distribution as Oolitic limestone. Mr. A. E. Cockerton, the County Surveyor of Oxfordshire, had shown him excellent roads made with such material between Oxford and Banbury, and Mr. Mager's experience pointed in the same direction. He had, however, seen slag being transported at great cost to places in the south of England where local stone might possibly have served just as well. A great saving in public expenditure might possibly be effected by experi-

menting in that direction. He had stated, in the detailed Report to the Government of Perak referred to above (p. 61), that "while laying down definite recommendations he had endeavoured not to dogmatise to the extent of suppressing experiment," a conclusion coinciding with that in the penultimate paragraph of the Paper. The problem, whether in Great Britain, on the Continent of Europe, or in Dependencies like British Malaya, was the same: not the design of an ideally perfect road, but how best, with limited funds, to provide the greatest possible mileage of reasonably good roads for the public use. That financial considerations were ever present in the Author's mind was shown from beginning to end of his Paper, and it was this quality that gave it its special value. Mr. Mager.

The problem of skidding had not been referred to, and, although he believed that a road test for drivers was the surest way of eliminating skids, yet the matter was one of public interest and might be discussed with profit. He regretted that rubber roads were not mentioned; while admitting that cost prevented their wide adoption, he believed that rubber provided the ideal surface and that, in special positions at least, it must ultimately be adopted.

Mr. R. A. B. Smith remarked that, unless he was under a misapprehension, the Author had designed a duplicate slab system of concrete road-construction, with the result that at certain intervals the road had no resistance to tension, and therefore a crack would almost certainly develop above the bottom joint. Again, assuming the best of foundations, a 3-inch thickness of concrete at each joint would be subjected under heavy traffic to a crushing stress probably beyond its limit. The Author compared the cost of asphalt surfacing 2 inches thick with the cost of 7 inches of concrete. Such a thickness of concrete included in itself its own foundation, and the cost of 12*s.* 6*d.* was extraordinarily high. Mr. Smith had found no case where the cost exceeded 10*s.* per square yard for such a thickness. In the Borough of Southwark, London, Mr. Arthur Harrison, M. Inst. C.E., had carried out an actual resurfacing of concrete on an existing concrete base, some of which had to be made good. The inclusive cost of this work was certainly less than 10*s.* per square yard. He believed that granite chippings and cement were used in the ratio of 3 : 1. The extra cost per square yard incurred by using British rapid-hardening cement was never more than 1*s.*, and by such means the road could be thrown open to traffic within 3 or 4 days. The saving of cost of watching for the longer period required for ordinary cement must be set against this extra cost of 1*s.* In the main road through the Tilbury Housing Estate there were two unreinforced longitudinal joints 6 inches deep and 1,100 feet long. These joints had been supervised by Mr. Smith. After a period Mr. Smith.

Mr. Smith. of 2 years there were no signs of the joint opening. It was sometimes stated that a good foundation was essential for a concrete road, but this did not agree with Mr. Smith's experience. He could cite 5 miles of road, 6 inches thick, constructed on Thames alluvial deposit, and another mile on peat land in Scotland ; in both cases the concrete road was serving its purpose, and in the former case another 5 miles had been constructed to practically the same design. It was far more important that the foundation should be uniformly good or uniformly bad, and in the latter case the concrete should be suitable reinforced.

Mr. Walker. Mr. J. H. WALKER considered that the Author's statement, that horses preferred asphalt to granite setts, exemplified in his experience of the road illustrated in *Fig. 4*, would have carried more weight if the relative positions of the asphalt and granite setts had been reversed. The difficulty with slow horse traffic on a cambered road was to make it keep close in to the near curb ; therefore, if asphalt instead of setts had been put down near the curb, and if it had been found that the horse traffic left the centre of the road for the reputed better travelling facilities of the asphalt, the Author's illustration would have been less liable to criticism.

It was stated that the concrete roads laid down in Sheffield were not reinforced, except in special cases. Assuming that the concrete was cast and anchored on to an uneven and perhaps porous formation, the shearing resistance between the slab and the formation would probably range between 3 cwt. and 8 cwt. per square foot. If the bays were of any considerable length or width, the omission of reinforcement would be likely to be a source of failure in winter when the concrete contracted. Apart from the questionable advantage of making the concrete road-crust in two layers, with new concrete placed upon concrete already set, it was arguable that the special precaution taken to prevent the joints of the bays in the top layer from coming over the joints of the bays in the bottom layer, was of itself a cause of failure. It would be reasonable to assume that each bay of the top layer would become keyed to two adjoining bays of the bottom layer, and that setting contraction of the top layer would cause a crack to occur at the only place at which the keying did not occur, namely, over the joint in the bottom layer. It would also appear possible for the bays of the lower layer to expand and contract, due to variations in temperature and moisture-content. If this were the case, they would do so against the resistance offered by the top layer cast and keyed on to them, and the cracks formed in the top layer during setting would become enlarged accordingly.

The cost of a concrete road, as given by the Author, was, of course, dependent upon the local cost of materials ; but in many places

1*s.* 4*d.* per inch thickness per square yard, inclusive of reinforcement, should be a generous allowance. In comparing the price of such a road with a 2-inch asphalt surface, it was to be recollected that the former was complete in itself, whereas the latter required a foundation, perhaps of concrete, at an additional cost. The Author's experience of concrete roads must have been unfortunate, as such roads, properly reinforced and constructed in one layer 8 inches thick and in bays 10 feet wide, with the joints interlocked, had proved eminently satisfactory for heavy traffic, with more than 4 years use, in spite of the traffic having in some cases to be put on them 2 days after completion. The experience, limited with regard to years of wear, gained with such perfected roads, wherein cracks and the consequent obnoxious grooving at the arrises thereof had been eliminated, pointed to a useful life of at least 15 or 20 years, probably much more. It was, of course, recognized, inasmuch as a rustless steel surface would wear and groove with the traffic, that it was desirable to protect concrete surfaces with a carpet renewable every 2, 3, or more years. Such a carpet, consisting of a thin bitumastic spray, powdered with granite chippings, and afterwards rolled, had lasted more than 4 years under heavy dock traffic before renewal. If too thick a carpet were put on, it would corrugate when hot and plastic in summer under fast heavy traffic, and become detached from the concrete. As the Author stated, it was advisable to give as long as possible for the concrete to harden. This was particularly so when small-size aggregate was used in the surface concrete. If it were necessary to open the road quickly, large-size aggregate should be used in the surface layer, and the use of special cement could be confined to the bays last laid, the less matured surface being protected against direct abrasion of the traffic by a temporary layer of sand or other loose material. Mr. Walker.

Mr. W. A. Willox remarked that, in his experience, for new roads, or existing roads whose foundations had given trouble in clayey ground under heavy traffic, a blanket of 6 to 12 inches of ashes or ground clinkers had been found very effective next the clay. Above this the usual foundation of hardcore should be laid. In new or resurfaced waterbound macadam roads only clean and uniform gravel or stone should be used, and this should be blinded with clean sand or fine stone chippings (or both). On no account should anything of a clayey or loamy nature be used. There seemed to be an idea that a waterbound macadam road needed binding with a sticky substance. That was not so. Once firmly consolidated, the individual stones became locked together and could not easily be disturbed. During the process of consolidation, however, plenty of clean sand should be spread over the road, which should be kept moist. In time the Mr. Willox.

Mr. Willox. sand was blown or washed away, leaving a clean, compact surface, which should be tarred at the earliest opportunity. Provided plenty of sand was used in the manner described, and a layer of stone not more than 3 inches thick was laid, the amount of rolling required was very little, the traffic doing the major part of the consolidating. All waterbound macadam roads carrying any appreciable traffic should be tar-dressed as soon after resurfacing as they were thoroughly dry. If that were done and retarring were carried out periodically, and if potholes were made up as soon as they formed, one surfacing should last for many years. Potholes, if they were not too big, should be dealt with in the following manner:—They should be dry to begin with, then swept clean and given a coat of hot tar no thicker than would be given to the ordinary road-surface. This should be sprinkled with $\frac{3}{8}$-inch stone chippings or washed gravel. After becoming quite hard and dry, the process might be repeated, if necessary, until the hole was filled level with the surrounding surface—on no account higher. If the pothole had become fairly large, it might be filled level with prepared fine tarmac. Excellent results had been obtained by using tar unmixed with bitumen, but with a small quantity of lime added (about 1 lb. to 2 or 3 gallons). It was essential to use only refined tar and to apply it hot to a dry surface, preferably brushed in, and sprinkled as lightly as possible with stone chippings or $\frac{3}{8}$-inch washed gravel. If crude tar, which usually cost no less than refined, were used, the result would generally be found unsatisfactory. When by any chance the tar had been spread too thickly and was slow in drying, it had been found advantageous to sprinkle it with fine smoke-box ashes. Having found refined tar, even without added lime—though lime was useful for preventing softening or for accelerating hardening in hot weather—quite successful, he had not used bitumen and tar mixtures to any extent. One objection to the use of bitumen was its unpleasant smell in hot weather. In his opinion, observation of the following conditions was essential in order to obtain good results with concrete roads. The aggregate should be absolutely clean, and only the quantity of water indicated by the slump test should be used. A layer of steel mesh or other suitable reinforcement should always be used, unless the foundation was absolutely above suspicion—a very rare circumstance. The whole mass should be in one layer. He was convinced that it was a mistake to lay concrete in separate layers. A fine surface, if required, could always be obtained by floating before the mass was dry. The concrete should be allowed to dry very slowly. This could be accomplished by spreading earth or sand or other suitable material over the surface, after the latter had set, and keeping it moistened for at least 3 weeks. The result should be a clean, hard

surface which should wear almost indefinitely, and would give a good grip to all classes of road traffic. Possibly periodical surface treatment with silicate of soda would be advisable, if traffic were heavy, but no other treatment should be necessary. Mr. Willox.

Mr. Francis Wood observed that the Author of this excellent Paper evidently intended that it should be taken as dealing in a general sense with the subject of modern road-construction, because no details were given to indicate the dimensions, grading, etc., of the various materials composing the road-surface. It was satisfactory to note that he advocated the use of bituminous surfacing in preference to other methods, which was a policy Mr. Wood had advocated for many years. He considered that this method of construction—notwithstanding its defects, which were not so serious as might be found in other forms—was the most satisfactory one known at present. Road-engineers would, he thought, consider that the Author presented a fair and reasonable view of the problem, and would agree with him in regard to such details as were mentioned, as to widths of roads, camber, etc. There were, however, one or two matters which might be discussed. The Author was inclined to view the traffic on roads as would be done on a railway; he also suggested that certain road-widths should be suited to certain tonnage, and that roads carrying a specified traffic should be constructed with certain materials: on these points there was room for a different view. Mr. Wood assumed that the roads with which the Paper dealt were main or through roads, and did not include those streets which local authorities called "private streets." In that case, any road which was subject to 2,500 to 3,000 tons per day might at any time have to sustain double that tonnage and even more. It was impossible to bring through roads into any category, or to assume that they would never be called upon to deal with a maximum tonnage, and there was more probability that such roads would have an increasing traffic. He had known roads where the heavy traffic had increased 400 per cent. in 5 years. Further, was there such a difference between the costs of roads to sustain 3,000 and 5,000 tons a day as to justify the variation? He doubted it. If a road was to withstand 2,500 tons, it should be constructed of material that would withstand 5,000 tons a day or more. A railway had pairs of rails, and the traffic was confined to the rails, hence the tonnage was a measure of the wear of the rails; but it was a different matter with a road subject to traffic which could move over its whole surface. Taking the illustration which the Author mentioned, and which Mr. Wood had had occasion to notice when traversing long lengths of main roads in this country, namely, that a negligible number of vehicles appeared to be moving either way, yet the tonnage was recorded as Mr. Wood.

Mr. Wood. being 1,500 to 2,000 tons per day, it might therefore be assumed that in such instance a vehicle took the central 5 feet of the width of such a road. Assuming that 2,000 tons passed over this road, the wear would take place over two narrow bands, about 5 feet apart, on the crown of the road; and if this tonnage was about the limit that could occupy the road without having to be diverted from this central position to any material extent, it was evident that, on another similar road of the same width with double the tonnage, repairs would not be necessary at any earlier time than in the previous case, notwithstanding that double the tonnage was being carried; because in the second case four tracks, roughly at 5-foot intervals, would take most of the wear. He assumed that half the traffic was in one direction and the other in the opposite direction. The obvious variations occurred when the heavy traffic left a town and the light traffic entered it; there was also the case where the traffic spread itself over the whole width of the road, which took place to some extent on a winding road and in towns, in which cases the road-composition should carry even greater traffic with less wear. Traffic tonnage was a useful guide to its intermittence or frequency; it might have some relation to costs of repair in similar roads and under similar conditions.

The road structure should be such that it would be capable of withstanding the heaviest type of vehicle that was permitted, with a high frequency. The same forces were at work in a road structure as applied in the case of a rail: both were subject to constant hammering, which had its effect on their life. The regulations applying to vehicles were so designed that the load per inch of tire was as nearly similar in all types of vehicles as could be devised; and therefore it might be assumed that, if the speed were the same, so would the relative tractive effort be the same per inch of tire in contact. The effect of a large number of light vehicles compared with a small number of heavy vehicles had never been determined, but the general opinion was that the light vehicle had not the same vibratory effect on the composition as had the heavy vehicle, notwithstanding that the tractive effort might cause greater abrasion when the light vehicle was travelling at a very high speed. The wear of a macadam road was due to two factors: the actual abrasion from vehicular traffic, and the effect of the weather and traffic in combination; the former caused only 15 per cent. of the total wear, 85 per cent. being due to the latter. The weather effect was eliminated to a large extent on modern roads, leaving the road structure to be worn by the vehicles. The rubber tire composition was frequently worn out after travelling about 6,000 miles.

Assuming that the tires were 33 inches in diameter and 4 inches

wide, in the case of the light vehicle the wear 1 inch on the back wheels, and $\frac{1}{4}$ inch on the front, the total wear of the tires would be 0·59 cubic foot. With a heavy vehicle wearing the back tires 2 inches and the front tires $\frac{3}{8}$ inch over a similar mileage, the total wear would be 2·1 cubic feet. Therefore, in a road structure subject to heavy wear of about 6 million tons per annum, that was, 6,000 vehicles per diem, two-thirds being light and one-third heavy, if the total wear of the road were equal to the wear of the tires of those vehicles, namely, 1·09 cubic foot per diem, or 398 cubic feet per annum, it would represent, if confined to four tracks 9 inches wide, 0·30 inch per annum. If the wear were distributed over a width of 9 feet, instead of being confined to 3 feet, the annual wear would be 0·10 inch. In the first case the four tracks would be worn 1 inch in a little more than 3 years, and in the other, in 10 years. Mr. Wood.

The best example of asphalt gave indications in this direction; Mr. Wood knew of asphalt, subject to steel-tired traffic, which had been down for more than 22 years. Victoria Street, Westminster, was laid more than 20 years ago, and some of the original material was still in the road. Asphalt roads with much less traffic, however, had to be repaired at an earlier date than was indicated above, and such repairs were not necessitated by tractive effort or abrasion, but by the unevenness of the surface; if it were possible to lay down a perfectly regular and even surface, and to retain it in this state, the wear would probably be in the above relationship or near thereto. But it was practically impossible to secure the necessary evenness, and however slight might be the unevenness, it caused the vehicle to rebound on the surface, with the result that wear took place through exhaustion of the vital forces in the composition by the numerous heavy and light vehicles constantly passing over it. It was possible to obtain a greater degree of accuracy of surface with mastic asphalt than with an asphalt in which the bitumen used was in a softer state than was employed in mastic, but the tendency of the mastic was to be more slippery.

The Author mentioned his success with the use of clinker from refuse-destructors. It was satisfactory to him that he was able to use that waste product, but it would not be advisable to assume that there was any particular virtue in such a material. The clinker varied with the quality of the refuse and the manner in which it was burned. Mr. Wood had seen clinker from a destructor that would crush under the pressure of the foot. The refuse which the Author used was, in his own words, "hard." Only recently analyses of samples of two bituminous surfacing mixtures were sent to Mr. Wood; they were supposed to be made so as to give the same results. One

Mr. Wood. was made from sand and cement, the other was made from clinker. The grading in the two cases was similar, but the striking factor was that the quantity of bitumen in the clinker sample was twice that in the sand sample. In a composition it might be that the proportion of bitumen was, say, 12 per cent., and its cost might be £1; the cost of the clinker would be probably 5*s*., as compared with sand, etc., at 10*s*. But, if only 25 per cent. more bitumen was required in the clinker composition compared with sand, no saving resulted in the total cost. Mr. Wood was inclined to the view that with an asphaltic bitumen almost any kind of mineral, provided it was suitably graded and sharp, could be used in a bituminous surfacing mixture; and, although this material might have a bearing on the manner in which the composition wore, the bitumen was the essential material, the mineral matter being the agent to hold the bitumen up to the traffic. Such a structure was, as a whole, resilient. There were striking illustrations that the cost of maintenance of roads reconstructed with a surfacing of asphalt was, even with a great increase of traffic, actually less than was the case with macadam before the war; and that, when non-recurring costs of the road structure had been paid for, the revenue from the taxation of motor-vehicles, as at present in force, would be considerably in excess of the total costs of maintenance. Mr. Wood had laid asphalt up to the tram-rails, and on the whole it was quite satisfactory. The tramway-track on concrete was a difficulty. Whether the cars in Blackpool were different from those elsewhere was a matter of opinion, but the rapidity with which corrugation appeared, even on sorbitically-treated rails laid on concrete, was not encouraging. Where, however, the rails were on a resilient bed—sleepers on a ballast underbed—the absence of both noise and corrugations was noticeable. This effect had a bearing on the necessity for a resilient road structure for ordinary traffic.

The Author. The AUTHOR, in reply, observed, with reference to Mr. Boulnois's remarks on the importance of specifying the number of tons per yard of width, that on p. 35 a standard width of 24 feet was mentioned, and on the following page this width was definitely related to cost statistics. With regard to the observation of Messrs. Boulnois, Smith, and Walker as to concrete roads in Sheffield, perhaps the Paper did not make the facts clear. The method of construction adopted had proved successful; the cracks (which did not appear over the bottom joints) were few and unimportant. The relative cost, however, was high, the disturbance of traffic on existing roads was lengthy, and where there was heavy abrasive traffic (and perhaps the test had been particularly severe on one of the Sheffield concrete roads), the wear and tear was very considerable. The Author's general view was that, before the concrete road under

really heavy traffic could be approved or condemned, it must have a much longer trial. The Author

It was interesting to compare Mr. Smith's suggestion, that if British rapid-hardening cement were used a concrete road could be thrown open to traffic in 3 or 4 days, with Mr. Willox's view that the concrete should be allowed to dry very slowly, and be kept covered with moist material for at least 3 weeks after it had set.

The cost of superimposing an additional thickness of concrete on an existing concrete foundation, and making good some of the latter (as cited by Mr. Smith) could scarcely be compared with the cost of an entirely new concrete road; and, though Mr. Smith considered 12*s.* 6*d.* per superficial yard an extraordinarily high cost, many concrete roads in various parts of the country had cost much more than this. A good deal depended on whether excavation and other items were included in other prices, as they were in the Author's.

With reference to Mr. Cattlin's remarks, it might be well to say that generally the Paper was not intended to deal with extremes, but with average conditions such as were met with by most road-engineers. Extremely heavy traffic justified a pavement of higher initial cost than could be considered by most provincial road-authorities, who usually were responsible for a long mileage, and, on account of the low rateable value, found the financial problem much more difficult than did an important metropolitan borough. It might be put briefly (and this also answered Mr. Wood's point as to providing for sudden increases in traffic) that the method of asphaltic surfacing described in the Paper, while its first cost was low enough to justify its use in a road with moderate traffic, was sufficiently durable for most roads with heavy traffic. The Author could not accept as a general conclusion Mr. Cattlin's statement that asphaltic carpets became wavy and corrugated in consequence of summer heat. No doubt Mr. Cattlin could refer to cases in point, but there were many other cases where such material had proved satisfactory over a considerable number of years. Waviness and corrugation could not be regarded as an inherent defect.

Two observations might be made with regard to the price of wood-block paving cited by Mr. Cattlin: first, that in London, where the larger paving contractors had very large areas under maintenance contracts, the price was naturally lower than in provincial towns, where similar conditions did not prevail; second, that the Author would not be satisfied with as low a maintenance period as 3 years.

Mr. Drummond had noticed newly-laid bituminous macadam roads showing considerable waviness before receiving any traffic at all. He attributed that to careless work, or over-rolling, or both. Mr. Boulnois thought the inception of waves was due in parts to

The Author. the use of heavy rollers. While agreeing with Mr. Drummond as to the necessity of skill, and in deprecating over-rolling, the Author's experience showed that the best results were obtained with a heavy roller, skilfully and judiciously used. Mr. Drummond referred to speed as a damaging factor, but the modern road must be designed for speed, and the new smooth surfaces, homogeneous in their character, were much less affected by speed than was sett paving or the old-fashioned macadam.

Mr. Mager summarized the problem of the road-engineer admirably in very few words, and the Author entirely agreed with him as to the usefulness of slag and some qualities of limestone, when mixed with a bituminous material; he had used both with success.

Mr. Walker questioned whether the horse would prefer asphalt to granite setts, if the respective positions of the two materials, as shown in *Fig. 4* (p. 33), were reversed. The Author had noticed that, while in one section of a busy granite-paved street the slow-moving horse traffic kept near the curb, in another section of the same street, where there happened to be an asphaltic centre, horses left the sett-paved margin for the smoother asphalt, to the inconvenience of the more speedy motor traffic. In that particular instance the horse traffic along the sides and central strip was counted, and the figures bore out the argument.

Mr. Willox was right in advocating a blanket of ashes or clinker over clay, but the Author could not agree with his view that a waterbound macadam road was not better for binding with a sticky substance—providing, of course, that the sticky substance was suitable for the purpose. Several chemicals had proved to be of great effect in improving the binding qualities of ordinary macadam.

Mr. Wood assumed correctly that the Author's remarks did not apply to "private" or merely residential streets. The Paper was intended to deal with roads carrying considerable traffic. The problem of the residential road was a different one. But the Author questioned whether Mr. Wood was right in assuming that in a road carrying 2,000 tons per day the wear was mostly confined to a central strip of 5 feet. While there could not be so much wear along the margins as near the centre, the Author's experience was that, even in a narrow road, traffic distributed itself over a much greater width than 5 feet. Although he had about 400 miles of road in his charge, he rarely saw ruts or cracks in a modern road. Where these occurred, they were usually caused by heavy vehicles taking the same line near the edge of the road, and not the centre. He agreed with Mr. Wood that the cost of maintenance of asphaltic roads, under the much heavier traffic of to-day, was less than that of the older types of road surface under the lighter pre-war traffic.