Discussion.

Mr. HAWKSLEY, Chairman, was sure the members would accord a hearty vote of thanks to the two Authors for their most interesting Papers, which gave a clear and excellent description of the latest type of a main line of railway constructed in this country. He regretted to say that the absence of the President and of Mr. Francis Fox that evening was due to a severe domestic bereavement, in which, he felt confident, the members would sympathize with them. Mr. Hawksley.

Mr. F. DOUGLAS FOX wished to thank one or two gentlemen who had helped him in the preparation of his Paper, viz., Mr. Rowlandson, of the Great Central Railway, for the loan of a map; Mr. Casson, the Resident Engineer of the Rugby section, who had helped him considerably; and Mr. Hutchinson, of the Catesby Tunnel section, and Mr. Lawrence White, of the Southern section, who had given him valuable notes of their own experience on the works. Mr. Fox.

The Authors then exhibited lantern-slides illustrating the construction of the railway.

Sir DOUGLAS FOX, President, wished to express his regret that he had not been able to be present at the reading of the Papers, and that Mr. F. Douglas Fox was absent that evening owing to illness. If any reply was necessary to questions that might be put in the Discussion he would be happy, as far as he could, to answer for Mr. Fox. The subject of the two Papers—descriptive as they were of one of the latest main lines of railway constructed in this country—was of so comprehensive a nature that it would be almost impossible to discuss them as a whole; but he thought there were several rather practical points which might be brought out in the discussion, and he merely mentioned them by way of suggesting to the members matters for their consideration. One was the comparative merits of end tipping and side tipping. A good deal of question upon that matter had arisen in connection with the very heavy earthworks upon the line. He did not wish at the moment to express any opinion, but he suggested the point as one worthy of discussion. Then it would be observed that prominence was given in the Papers to the subject of the general drainage of the earthworks; and, considering the character of the Sir Douglas Fox.

Sir Douglas Fox. strata passed through in many parts of the line, it was believed that a great deal of the success achieved had followed from the introduction of adequate drainage, especially at the tops of the cuttings. Another interesting point was the curves which were permissible on a main line for fast traffic. The minimum radius for the curves on the Southern Division, with one exception, had been limited to a mile, and it was found that with that radius trains could travel at very high speeds without any detriment to their stability or the comfort of the passengers. One other subject he wished to mention was the question of island platforms for roadside stations as against side platforms. It would be observed that on the new railway the system of island platforms had been very extensively adopted, and that, he thought, was a question well worthy of discussion amongst engineers.

Mr. Middleton. Mr. J. T. MIDDLETON thought the Papers brought out many points which were frequently arising in railway construction. The works were of the usual type, but deserved perhaps more attention than ordinary works, owing to their magnitude. The amount of all classes of work carried out on the Great Central Railway, and the rate of progress, had probably exceeded anything previously attained. There were a few points in the construction, however, which presented somewhat novel methods. By reason of the line crossing the "roll of the Midlands," as it was called, at right angles, very heavy earthworks had been entailed, and consequently the question of slips had demanded the attention of the engineers. Mr. Bidder had referred in his Paper to the treatment of slips in embankments and cuttings by a system of drainage which he described as having the appearance of piers and arches in a viaduct, the vertical drains being connected at the top by a series of arched rubble drains. He could not see that the arching of the drains really was any great advantage, except of course that the top of the slip was thereby supported; and as far as his experience went, the provision of good-sized vertical drains going well down to the bottom of the slip, and extending right up to the top of the bank or cutting, as the case might be —or, at any rate, as far as the slip was observable—with diagonal drains striking out of them, was a more effective method of treating the slips. Greater efficiency was obtained in these vertical drains when they were made to taper on plan, having a greater width at the bottom than at the top and thus forming a sort of wedge-shaped counterfort, which tended to prevent the slipping of the earthwork. The question of end tipping *versus* side tipping, which had been referred to by Mr. F. Douglas Fox, applied, he presumed, only

to large embankments, such as had been dealt with upon this line. He knew there was a prejudice against side tipping, and he thought it arose chiefly from the older practice, as it might be called, in the use of side wagons and side tips in forming embankments. In that case side tipping applied practically only to the filling up of the spaces formed between the end-tipping roads upon which the wagons were tipped. Those roads as a rule were 14 feet or 15 feet apart; and there was a triangular space left between each two roads. The use of side wagons hitherto had been—and, in ordinary practice on works of a smaller character than those under discussion, was—to fill up these spaces: also where a bank had been tipped rather narrower than it should have been, side tipping had to be used to make up the extra width. In both those cases there were no doubt objections, especially to thus widening a bank which had been tipped some time, in which case the extra width was put on to a more or less consolidated surface; and unless benching and other precautions were adopted, the application of side tipping in this way was likely to cause some difficulty with regard to slips. His experience, especially upon the southern section, where the banks were very heavy, with flat slopes, causing them to be exceedingly wide, made him decidedly of opinion that side tipping as now carried out on such works was far superior to the old end-tipping arrangement. In a large bank, say 50 feet or 60 feet high, tipped in two or three lifts, and having slopes of $2\frac{1}{2}$ or 3 to 1, the bottom lift was a very wide one. By the method of end tipping in such a case, there would probably be in the lower lifts, say, a dozen end-tipped roads, 15 feet or more apart, with eleven triangular spaces between them. Those spaces, as a rule, were filled by the larger lumps of tipped earth which had fallen to the bottom at the end and at the sides: they were afterwards levelled up by side tips or by casting out, and thus the bank was composed of hard and more or less soft places, the hard places being those over which the wagons had been run and tipped in each end-tip road, and the softer places being those between the roads. That caused very unequal settlement of the bank; for the earth in the spaces between the tipping-roads was not consolidated by the passage of wagons over it, and water readily accumulated there in a wet season; and he ventured to say this was the cause of many extensive side slips. In railway embankments which, after having been tipped for some time, had settled through bad weather, large holes, in which a horse could be buried, would very often be found at places in the bank where the space between tipped roads had been filled. The advantages

Mr. Middleton.

Mr. Middleton. he claimed for side tipping were the following:—In starting the construction of an embankment on this plan, the work was commenced at the surface and at the outer edge of the slope. Side tipping went on, and the roads were gradually lifted and slewed until such a height was attained as had been fixed for the level of the first lift. Then side tipping proceeded right across that lift. He maintained that in this manner the impact of every train-load which passed over the embankment helped to consolidate it uniformly. There were no loose or open spaces such as might be found between end-tipped roads, the whole of the embankment receiving the benefit of the weight of the trains. The only danger he could see arising from it was, that when the outside tip was reached to form the full width there was rather a change of circumstances. The slope at which tipped material naturally stood might be said to be about 1 to 1. Supposing it was required to form eventually a slope of 2 to 1, that necessitated tipping it out a little farther, so as to have sufficient material to trim down; but if it was trimmed down without any great delay, there was no danger of slips, even on the outer loose end of the side-tipped bank. If it were allowed to remain there for months, it might cause trouble, but no more than would arise under the same circumstances in end tipping, because the side of an end tip could not possibly be tipped to such a flat slope as $2\frac{1}{2}$ to 1, which was a very common slope in embankments on the Great Central Railway, owing to the stuff that was in them. If end-tipped, it would have to be tipped with sufficient material to trim down to form a 2 to 1 slope; and if that were left, there was no doubt it would drag material away, and be the means of causing a slip. He had had an opportunity of judging from material taken out of the same cutting and tipped into two banks, one an end-tipped bank by the ordinary process, and the other a side-tipped bank such as he had described; and he had found that, while in the end-tipped bank large holes had been formed and the settlement on the bank had been certainly most unequal, in the side-tipped bank this obtained to a much less extent. He did not consider the suggestion made in Mr. Fox's Paper, that a narrow end-tipped bank should be tipped in advance for side-tipping purposes, to be of much advantage. From his own point of view, it certainly had great disadvantages —it involved additional cost, and the provision of two distinct sets of plant in the same cutting. He presumed the idea was that it contained the side-tipped material on one side, but he did not think this at all necessary. In advocating side tipping, he

Mr. Middleton.

was referring not to the old side tipping, but to the side tipping practised within recent years in the construction of heavy embankments: for a single line of the ordinary description he would say it was absolutely out of the question. A further consideration arose, which, he thought, ought to weigh with engineers generally, namely, that where there was a large quantity of earth coming out of a cutting which could not be worked from both ends, and the whole of the excavated material had to go into one large bank, far more rapid progress could be made by side tipping than by end tipping. There were several cases of this kind on the southern section in which between 60,000 cubic yards and 70,000 cubic yards per month was tipped into one bank from the same cutting. That was almost impossible with end tipping. He thought a point of this kind was a very important factor in the rate of progress of work in these days, when, no matter how long the promoters had been considering the scheme, when once it was put in hand they wanted it done in the shortest possible time; and it was undoubtedly important that every facility should be afforded to those who carried out the works. With regard to slips in cuttings, there was one source which, when excavating by steam-navvies, was very often probably not sufficiently considered. A steam-navvy was designed to excavate a certain cutting, the bottom of its cut being coincident with the slope at the level of the top, second, or third lift, as the case might be. The machine was driven through and the bulk of the cutting was excavated, but the wing or slope muck which the machine could not reach was left behind until a convenient season, and then it was lifted by hand. In excavating with a steam-navvy there was a slope of something like $\frac{3}{4}$ to 1, and the difference between that and the eventual 2 to 1 or $2\frac{1}{2}$ to 1 was the wing muck he referred to, which ought to be excavated and carried away not much behind the cut of the navvy. Instead of that, it was left practically hanging, and there was no doubt at all that in certain materials it dragged and was a fruitful source of slips in cuttings. On the southern section there were between 4,000,000 cubic yards and 5,000,000 cubic yards of earthwork, and the system of keeping the slopes roughly trimmed close up to the machine, together with the excellent system of heading-drains, had resulted in the fact that there had been very few slips in railway cuttings, and in no case had there been an extensive slip in a big cutting. Mr. Bidder had given some interesting information in his Paper with regard to the subsidence caused by coal-workings, and had referred to a bridge which settled 3 feet

Mr. Middleton. without any signs of fracture, which spoke highly for the work. It would have been more interesting if he could have given some indication of the thickness of the coal-seams, and their depth below the surface, from which an idea might have been formed of the effect of the action which took place. He hoped Mr. Bidder would further enlighten the members as to the methods adopted for the support of the buildings tunnelled under at Nottingham, and also state the depth of the tunnel below the buildings. That was an important question, especially in London, where tunnelling was proceeding in close proximity to large, important and valuable buildings; and he was sure that any information Mr. Bidder could give on such matters would be of great value to the Institution. Both the engineers and the contractors were to be congratulated upon having attained a record of progress in the Catesby Tunnel. It would certainly be interesting if Mr. Fox could say something more about the number of faces worked, the methods of ventilation adopted, and other points in connection with the progress of that tunnel. One point which seemed to him rather a novelty in the treatment of foundations of bridges and viaducts was referred to by Mr. Bidder, namely, the laying of courses of bricks on the foundation before putting in the concrete. He had not himself seen any method of that kind adopted, and he would be very glad to hear that it was useful and effective. Mr. Fox had invited discussion on one other point, namely, the use of burnt ballast in concrete. His own opinion was that good, well-burnt clinker-ballast was an excellent material, mixed, of course, with sand, for making concrete, especially in such a district as that in which the works under discussion were situated, where no other material could be obtained; and also for mixing mortar, where clinker-ashes and sand were not to be had. Burnt ballast was certainly in no way deleterious to work. It had been used largely on the southern section of the line, where there was no gravel and very little stone, and that only at one place; and he knew of no instance of failure. The method adopted in crossing over the Oxford Canal near Rugby, where the navigation had been conducted in a steel trough, appeared to him to be unique, and he knew from his own observation that it had been entirely successful.

Sir Leader Williams. Sir E. LEADER WILLIAMS said that the question of end and side tipping was one about which engineers differed, and he did not think an absolute rule could be laid down to be followed in all cases. The engineering profession had to adapt itself to all circumstances. Where there was sound ground to work upon

and good homogeneous material suitable for a high bank, he did not think the method of tipping made any difference whatever. His experience on the Ship Canal at Manchester, where between 45,000,000 cubic yards and 50,000,000 cubic yards of excavation had had to be made, a large part of which was run to high embankments, aggregating about 8 miles in length, to enable railway viaducts to be carried over the Ship Canal, was certainly very favourable to side tipping. The contractor, Mr. Thomas Walker, had gone to large expense in putting heavy plant on the works, and he had included a large number of side-tipping wagons. In his early days, when he had been Assistant Engineer under Sir William Cubitt on heavy embankments on the Great Northern Railway near Gainsborough, nearly 50 years ago, his usual custom had been to run end-tipped banks well ahead and follow up in the centre, a plan which was rather captivating. With a good piece on either side the centre could be filled up, and it could be easily understood that with good material it was a nice way to make a bank. Those embankments had been on difficult boggy ground just before the Trent was reached, and there had been considerable difficulty in carrying any drainage underneath. Culverts very soon had to be given up, and the difficulty had been met by the use of large cast-iron pipes with spigot-and-faucet joints and india-rubber rings something like 3 inches in diameter, which had made the whole thing very elastic. When the bank had been tipped over the pipes, they had raised themselves up vertically on each side of the bank, and horizontal ends had been obtained, which had rendered the method of constructing the culvert-ends a rather puzzling problem. The bank had given no trouble afterwards, although it had been tipped in that way. If he had to deal with boggy ground of that sort again he was not at all sure he would not prefer end tips; but when he mentioned that in the 8 miles of embankment formed from the excavation of the Ship Canal, and done almost entirely by side tipping, there had been no slips or trouble whatever, he thought very little could be said against the system. One of its advantages was that it was possible to tip with much greater rapidity than by end tipping. A train of twenty or thirty wagons was used, which were all brought into line; the tippers then used the levers, and the whole was shot out at once. At the same time he was bound to say that the material used in the Ship Canal embankments had been very good, and there had been no boggy ground to put the banks on. He might mention a very interesting feature of the Great Central Railway

Sir Leader Williams.

Sir Leader Williams. works which perhaps might be useful to engineers whose practice had been identified with canals. The railway crossed the Oxford Canal at a considerable elevation, and the canal was on an embankment; the piers had had to go through the embankment, and other things had not been very favourable. The work had been successfully carried out, and he thought the way in which the difficulty had been overcome by means of an iron trough was ingenious. He had been struck with the fact that the engineers had wasted nothing, Sir Douglas Fox having used up the old trough afterwards for a footbridge over the line.

Mr. Fox. Mr. F. G. B. Fox said one of the members had spoken about side tipping, and he had had experience in Madras and Northern India of cuttings in which the strata varied considerably. If the earth obtained from the cuttings was of one quality throughout, side tipping was doubtless a very good thing, but in cuttings 80 feet or 90 feet deep the quality of the earth often varied. Many years ago a slip had occurred on the Madras Railway, owing to a large accumulation of water between the different layers of earth in an embankment which had been made by throwing up a bank in the centre and tipping on its sides. The whole side of the bank had been washed away, and the line had subsided and caused an accident. That was an illustration of one of the disadvantages of side tipping. If tipping were started from the bottom, and spread all over, that would be avoided. With regard to brick ballast, in India there were many thousands of square miles where no stone of any kind whatever was to be obtained; and engineers there had to use broken-brick ballast for concrete, as well as for road-metal and other things, and they never found any difficulty with it. He thought clinker ballast was quite as good as any stone for concrete. It might not be quite so heavy, but he had broken the concrete 9 months old, and the ballast had showed as if it had been cut through with a knife, the mortar having adhered to it so firmly. In the mortar itself the brick or burnt clay combined chemically with the lime and formed a hydraulic mortar. It was well known that pozzuolana had been used in Europe for many years, and he did not see that there was any objection to it.

Mr. McDonald. Mr. J. A. McDonald remarked that the question of using burnt ballast for concrete was a very old one, and one often arising. There was no doubt that concrete made from burnt ballast was much lighter than that made from gravel or broken stone; but, on the other hand, if the ballast was well burnt and used with lime, not cement, the result in concrete was an extremely good

material. He saw in the room Mr. Richard Johnson, who, he thought, had built more walls of concrete made of lime and burnt ballast than anybody else, and he felt that the Institution would be glad to hear Mr. Johnson's views on the subject. About a couple of years ago, when he had been widening the portion of the Midland Railway between Kentish Town and St. Pancras, he had had occasion to pull out some very large masses of concrete formed of burnt ballast and lime, which had been put in at the back of the walls built by Mr. Barlow 25 or 26 years before. The walls had moved in consequence of a very extensive slip, running back a long way from the railway, and moving on a slippery bed which made a very slight angle with the horizontal. On the walls showing signs of movement, the large masses of concrete had been put in. He believed they had been all formed of about 5 or 6 to 1 lime concrete made (in most cases) of the actual material excavated to form the holes into which the concrete had been put. When the walls had come to be pulled out great difficulty had been experienced. The concrete had been comparatively light, but so tough that the contractor had had the greatest trouble in getting it out, and he thought he was safe in saying that by the time it had been loaded into the wagons there was very seldom a piece measuring a cubic foot. He thought that showed that when lime was used—he did not like burnt ballast with cement—the resulting concrete was a very useful material, and there were many ways in which it could be adopted successfully. Mr. McDonald.

Mr. RICHARD JOHNSON had used a great deal of burnt ballast in concrete and also in building walls, principally in the neighbourhood of London, and he had no hesitation in saying that burnt ballast, say 25 per cent. of burnt ballast and 75 per cent. of good gravel with cement, made very good concrete. Mr. McDonald had spoken rather slightingly of cement, but his experience was that cement made a very good concrete indeed. Mr. Alexander Ross, was just now about to pull down some walls which he (Mr. Johnson) had built a few years ago, and he wished Mr. Ross every success in getting them to pieces. He was sure he would find that there was a fair proportion of burnt ballast in those walls, and he hoped the members would not be afraid of cement in concrete. No doubt cement did play tricks in brickwork sometimes. As was well known, it required a good deal of humouring and keeping before it was used. With regard to Nottingham Station, his friend Mr. Parry had prepared innumerable plans for that station. Originally it had been designed as a one-company station, and Mr. Johnson.

Mr. Johnson. there was to have been one island platform. It had been his misfortune to be in opposition, and he had said there must be two. The Great Northern Company were joint owners, and he had said that to construct a station with one platform for two rival companies would never do. Eventually the point had been carried and two platforms had been built. There was at Nottingham a weak point on the Great Central Railway. From the section it would be seen that Nottingham Station was approached from the north by very long tunnels, having only two lines of way. He had often said to Mr. Parry that he ought to construct four lines of way at that point; for the experience of the last 40 years had been that the great railways of this country had been throttled by the insufficient tunnels which had been constructed in the early days. Of course, Mr. Parry had said he had no money for more, and that he had been obliged to be satisfied with two-line tunnels. Nevertheless, that was the weak point, in his opinion, in the Great Central Railway as a trunk line. At a place like Leicester, where the ground was perfectly open, it was possible to double the railway easily. During the last 30 years he had had to carry out many additional tunnels on the Great Northern Railway. It had been found that without those tunnels trains were delayed, and the four lines of way were of comparatively little use; and eventually additional tunnels had been, and would have to be, constructed so as to give a free course to the traffic. In the case of the Great Northern Railway the members were probably aware that in the Session of 1897 power had been obtained to construct an entirely new railway from Stevenage to Enfield, so that on the part of the Great Northern Railway south of Potter's Bar where the long tunnels were, additional tunnels would not be constructed, but an entirely new line from Stevenage to Enfield, joining the existing railway at Enfield, would give freedom to the traffic.

Mr. Sadler. Mr. H. W. SADLER remarked that he was in the unhappy position of having to pull down the walls in the neighbourhood of Finsbury Park to which Mr. Johnson had referred, and was therefore able to speak as to the quality of cement walls made with burnt ballast. Concrete made with burnt ballast was certainly very good, but it did not take so much pulling down as that made with gravel, and he thought this was owing to the softness of the ballast. It was found that almost the only place where the walls could be broken up was at the junction of the layers. When built they had been carried up in 12-inch or 18-inch layers, and by driving wedges between the layers the top

broke up and the walls were thus removed. That seemed to show that concrete, in walls at any rate, should not be built in layers, and an endeavour was being made in the walls now in course of construction at the back of those to which Mr. Johnson had referred, to leave the layers in the rough when leaving off at night, so as to form a key for the work on the following day. There was only one other point he wished to mention, and that had reference to the sorting-sidings at Annesley. Looking at the diagram, Fig. 2, Plate 1, it would be seen that, in the sorting-sidings on the up side, the wagons came into the reception-sidings at the north end, ran down into "departure" or sorting sidings (commonly called the "grid"), and thence passed out by the south end. He ventured to think that was the right system. On the down side, however, it would be seen the wagons had to go northward by what was called the arrival road into the reception-sidings; then they had to be run southward down the reception-sidings into the dead-ended "departure" or sorting-sidings, and finally they had to travel back again to go away to the north. Every wagon had to pass the point just below the repairing shops three times, and the shunting had all to be done over the same neck. As Mr. Johnson would remember, when the sidings had been laid out at Colwick—and the sorting-yard there was one of the largest in the kingdom, if not the largest—an exactly similar arrangement had been made for the wagons going down the line with "empties," and it had been found that so many delays occurred at the "bottle neck" that the Great Northern Company had had some time ago to spend a large sum of money in making a fresh set of sidings on the system of those shown on the up side. He had had the pleasure of carrying out the alteration under Mr. Johnson, and it had been found to work very well. The proper system for gravitation-sidings was for the wagons to be run in at the top or arrival end of the gradient, and down to the bottom or departure end, towards their destination; and "dead-ended" sorting-sidings were always a source of trouble. He knew Mr. Parry's difficulty at Annesley had been the gradient. As would be seen from the section, it ran down from north to south 1 in 132, and no doubt considerable expense would have had to be incurred to make an incline up so that the sidings would have run from south to north; but he ventured to say the Great Central Company would regret some day that they had not gone to that expense. Mr. Sadler.

Mr. JOHNSON was very glad Mr. Sadler had made that remark. He thought the weak point of those sidings was at that place. Mr. Johnson.

Mr. Robertson. Mr. F. E. ROBERTSON remarked, with reference to what Mr. Sadler had said about partings in the wall, that at the end of the day's work in building a concrete wall it was always expedient not only to rack the work back in steps, but also to leave in some good big stones to form a key to the next day's work, and so avoid the defects found in pulling down walls where a plain surface had been left. With regard to the use of burnt clay in general, in some parts of India that was the only material available for ballast and for concrete; and he thought it was as good as most stone if, instead of burning the clay in lumps, the precaution was taken to first mould it into tiles about 12 inches square and 1½ inch thick. They could be cheaply slop-moulded on the ground slightly smoothed. The tiles were easily vitrified, easily broken, and very good both for ballast and for concrete.

Mr. Galbraith. Mr. W. R. GALBRAITH thought it was a pity that, having regard to the great importance of the line, the Great Central Company had not seen their way to construct the last two miles of the line, between the neighbourhood of South Hampstead and their terminal station, with four lines of rails at once. From a little to the north-west of Swiss Cottage there were only two lines, and having regard to the somewhat unfortunate state of matters between the Great Central and Metropolitan Companies, it seemed to him that the Great Central had to depend mainly on their own line for their traffic. If the traffic increased, as everyone expected it would, and especially if the passenger traffic increased with the goods and minerals, it would be soon found that the two lines of rails were quite inadequate, and the company would have to double them at a considerable cost. The big companies now running into London had had occasion not only to double, but sometimes even to treble their lines; and he thought his old master, Mr. Locke, had been wise when he had made the London and South Western line from Vauxhall into Waterloo with four lines of rails something like 50 years ago. The South Western Company, for their passenger traffic alone, had been now obliged to make that into six lines, and even those were hardly sufficient for the traffic. Therefore he thought the Great Central Company would have been wise if they had spent more money in making at once four lines of rails into their goods and passenger stations. With regard to curves, his impression was that the minimum radius adopted might very well have been diminished. He thought a radius of 60 chains, or ¾ mile, would take traffic at any speed which could be run. On the London and North Western line to Scotland, and on the Caledonian line, very high speeds were

attained down the inclines, the running over 60-chain curves being effected with perfect facility, and without any disagreeable swing. On some of the lines of the North British Company, from the Forth Bridge northwards, there were curves of considerably shorter radius; in particular on the Glenfarg line leading to Perth, it had been necessary, for the sake of economy, to put in a long 30-chain curve. Over this the trains frequently ran at 60 miles per hour, apparently with very little discomfort. He thought, therefore, he would not have hesitated to put a 60-chain curve on the main line. Mr. Galbraith.

The PRESIDENT said it should be remembered there were reverse curves. The President.

Mr. GALBRAITH thought if there was a proper length of straight between the two curves no great inconvenience would be found. He believed his friend Mr. Hawkshaw contemplated a railway between Liverpool and Manchester, where the speed was to be something far beyond present experience in this country—he thought at least 100 miles an hour. There the curves were hardly so flat as 60 chains radius. If anything was to be gained by the introduction of 60-chain curves he would not hesitate at all. There was no doubt that for the easiest and steadiest running a curve with a radius of about 2 miles was superior to anything—far better even than a straight line; because there was less oscillation, practically no extra resistance, and a slight bearing on the outer rail, which seemed to steady the train when it ran at high speed. Nothing could be more splendid than the goods station at Marylebone Road, with all its appliances. Everything seemed to have been laid out without regard to cost, and in the most satisfactory way. He only wished the passenger station were filled with traffic, but no doubt that would come in time. With regard to the permanent way, he gathered that where stone ballast was available, large stone about 9 inches in thickness was laid on the formation. He did not quite understand what amount of small ballast there was above that. If the ordinary thickness of 12 inches of ballast below the sleepers was the rule in that case, it seemed to him there was hardly enough small ballast above the heavier ballast to pack, especially as contractors sometimes read "a 2-inch ring" rather freely. No doubt some heavier stone in the bottom was a good thing for drainage, and he thought there ought to be at least 5 inches or 6 inches of smaller material or gravel above, to sufficiently pack the permanent way. Mr. Galbraith.

Mr. J. C. INGLIS thought the fact of the Papers coming at that Mr. Inglis.

Mr. Inglis. moment was a very fortunate circumstance for the Institution's Proceedings. There was no doubt that as time went on they would become more valuable as being a complete record of the construction of a first-class line, 90 miles in length, in this country. He hoped, therefore, that the Authors would give more detailed particulars of the permanent way, especially of the rails, and of the permanent-way fastenings and fittings, which were not the least important items in the construction of an express line in the year 1900; and he would suggest that some information on these points should be added. He had had a good deal to do with express roads, and he found there were very great advantages in using rails longer than 30 feet, an opinion which he believed was confirmed by experience on all the leading lines in this country. The London and North Western Railway had led the van in the matter of length by using 60-foot rails, and on the Great Western Railway rails 44 feet 6 inches long were being used. The advantage gained was more than that of mere reduction in the number of joints to be looked after: the road was safer and more easily maintained. When the discussion had been going on as to whether longer rails should be used, the great objection brought forward had been the waste which would occur when rails broke, and when faults occurred; but really the number of breakages was so few with the heavy rails now in use that the question of waste on this account could be fairly put aside, because even if a long rail did break it was not necessarily wasted. Another important point connected with the permanent way was that, in his experience, sleepers placed 2 feet 6½ inches apart produced a more easily maintained road on a long line than sleepers placed 2 feet 9 inches or 2 feet 9½ inches apart, as they were on the Great Central Railway. It was well known that the weakest point in permanent way was the bearing of the sleeper upon the formation. That was the point which gave out soonest, and smooth running was dependent on the diligence and the ability of the permanent-way men to pack up the slack at that point where depressions occurred. His experience in a very definite way, trying it first experimentally and afterwards as a practice, had been that the small change of putting the sleepers even 3 inches closer together had had a wonderful effect in getting over that point at which apparently in many parts of the line the impact of the passing engine and carriages had been enough just to indent the sleepers somewhat into the formation. Of course there was also the shorter span to be taken into account. He was quite prepared to show in detail that it paid to put the

Mr. Inglis.

sleepers somewhat closer than they had been put on the Great Central line. He thought there had been a noticeable absence of reference to money in the Paper under discussion, and he hoped the Authors would give an analysis or statement of the cost in such a way that the cost of the main line could be separated from the cost of the stations, large or small, and particularly the small ones. This information would be interesting to members who had to deal with main lines, and he thought the omission could be easily rectified. The question of the island station-platform was very interesting, because it followed from the adoption of a central platform that the working of the line when it was doubled, that was when four lines were laid instead of two, would more than probably be by two up lines and two down lines. As the members were aware, there were many long lengths of express lines where there were four lines worked with two up and two down lines. The designers of the Great Central Railway and the traffic-officers of the company had decided that if anything was to be done it would be in the way of two up and two down lines; and he was bound to say that in that case he agreed with them. In this as in many other matters, particularly the question of the accommodation at such a station as Nottingham, or the question of the best arrangement of sidings at such a place as Annesley, so much depended upon the traffic at those particular points that it was very hard to criticise the proposition as a general principle. But with regard to smaller stations perhaps it was not so difficult. In his judgment the question of whether the two up and two down lines in a four-lined road should be adjacent depended entirely on the character of the traffic. He could imagine circumstances under which it would be wise to adopt such an arrangement, viz., where there were few junctions. On the other hand, the arrangement of alternate up and down lines had advantages where it was possible to deal with local and goods traffic on one side of the railway, and to leave the other two lines freer for the passage of express trains. He was greatly interested in the question of end and side tipping, because it so happened that his company were making the South Wales direct line, where there were very heavy banks, and that question had forced itself on his attention. The conclusion he had come to was that, if it was prescribed and arranged that the lift in a high bank should not be excessive, he would be inclined on the whole to prefer going on with the end-tip wagons. He thought it was easy to overdo either end tipping or side tipping by making the lift too high, but if the work was carried out in layers, as it were, the

Mr. Inglis. result would be satisfactory. He was quite sure that whether the bank was to stand or to be troubled with slips depended a great deal on the uniformity of the material of which it was formed. He had in his mind a very high bank with which, except in one part, there had been no trouble whatever. That bank had been tipped in lifts of about 20 feet, and it had been possible to trace the trouble which had arisen at one point to the material which was tipped having come from an unsatisfactory part of the excavation. The question of the treatment of banks also depended very much indeed on local circumstances and on the material dealt with. The line he had referred to was being laid out with curves of 1 mile radius. Every day trains passed over 25-chain curves at a speed of 60 miles per hour, but he thought no one would say that was a satisfactory practice. The principal point which he looked at in a curve of 80 chains, or 1 mile, radius was, that it was not quite fair to the drivers of express trains to provide unnecessarily sharp curves. His experience was that uniform speed could not be obtained from the engine-drivers when they could not see ahead. One man would go full speed ahead and another would not; but if the drivers could see a fair distance in front there was greater uniformity in the running at a high speed, and he thought that was a point which should not be lost sight of. In going at a mile a minute, no sooner did an engine-driver sight a signal than he was close upon it. He quite agreed with Mr. Galbraith about the necessity for having straight lines between the curves. He had a case in which numerous complaints were being made about the travelling and jolting on a line, apart from the permanent way, and the curves there had been examined. There was no curve with a less radius than 30 chains; the majority of them were 40 chains; and the unsatisfactory running on that line at a fairly high speed was solely due to the fact that it was set out without any straight between the reverse curves. He was satisfied that the trouble had arisen entirely from want of precaution on the part of the engineer in not having, say, twice the length of the train between the reverse curves.

Mr. Bidler. Mr. F. W. BIDDER, in reply to the Discussion, said that details of the methods adopted for the support of the buildings tunnelled under at Nottingham had been asked for; but as no particular system had been used throughout the work it was difficult to give anything like a complete description of the various methods employed, each case as it occurred having had to be treated in a manner suited to its requirements. The depth from ground surface to the crown of the tunnel varied between 8 feet and

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20 feet, and the springing of the arch was on the solid rock throughout. A large number of rock cellars under the houses, of various shapes and sizes, had been cut through, and these had been first of all carefully located, measured and plotted on the working-plans, levels being also taken so that before tunnelling operations were commenced each particular case could be well considered and the necessary steps could be taken to insure the safe upholding of the buildings above while tunnelling was in progress. Where brick walls and sand-rock piers had had to be supported, small holes had been first cut, through which timbers had been inserted and temporarily supported upon the cellar-floors, clear of the space required for the tunnel crown-bars, the brickwork or rock-pier being then tightly wedged up off the timbers. As the lower portions of the brickwork and sand rock had been gradually taken away, other and larger timbers had been placed in various positions, so as to enable them to be supported upon the crown-bars as they were put in the length of tunnelling being excavated at the time. When the excavation had been completed down to springing level, the building of the arch had been commenced, care being taken to wedge up the timbers off the brickwork as it proceeded and before the crown-bars had been struck. In this case the crown-bars had not been put high enough to allow of their being drawn after completion of the brickwork, as was the case with ordinary drawing-bars, but had been kept down within 9 inches of the soffit of the arch, so as to clear the ribs and lagging, and consequently they had had to be removed as the brickwork proceeded. The reason for adopting this method had been to minimise the unavoidable interference with the buildings above the tunnel, and also in some cases to preserve as much of the solid rock over the crown of the arch as possible; as where ordinary drawing-bars had been used the excavation had had to be taken out considerably larger than had been actually required to take the arch. It would thus be understood that it had been very necessary to carefully transfer the weight upon the timbers carrying the walls and piers of the houses off the crown-bars and on to the brickwork as each successive bar had been worked up to. This had been accomplished by means of temporary brick piers and timber packings. When the brickwork of the arch had been completed for some considerable time—generally varying between three weeks and a month—and after the centering had been removed and the arch had taken its proper bearing, the underpinning of the cellar-walls and rock-piers had been proceeded with, brickwork in cement mortar being used, resting on the

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The use of several courses of dry bricks in the bottom of wet foundations, where pumping was necessary, had also been referred to. By the adoption of this plan, which had been found both useful and effective, the concrete when put in position was kept above the level of the water by the courses of bricks, which allowed the water to flow freely through the open joints towards the pumps without in any way touching the concrete. The number of brick courses required depended upon the quantity of water to be dealt with, but was usually three or four, as allowance had to be made to avoid as far as possible the water rising in the foundations during temporary stoppages of the pumps from reaching the level of the concrete.

Comment had been made upon the fact that the tunnels approaching the Nottingham Joint Station had been constructed for two lines of way only; but this was a question which had received every consideration in laying out the line. The present tunnels ran as far as possible under the streets of the city, thus avoiding the cost of purchasing a considerable amount of valuable property, and there would be no great difficulty in providing an additional tunnel alongside those already existing, should it at some future time be considered desirable. Mr. Parry had long ago suggested the construction of a short loop line outside the city, over which the through traffic could be conveyed, and which would in all probability be found less expensive and more satis-

factory in working than duplicating the existing tunnels, as not only the tunnels but the station as well would be relieved of this traffic, and delay would be avoided in passing through the city. Mr. Bidder

Attention had also been drawn to the manner in which the down sorting-sidings at Annesley had been arranged, and the objection to the wagons having to shunt back into the departure sidings, instead of travelling forward as on the up side, had been pointed out. This, of course, had been well understood, and the plans originally prepared for the gravitation sorting-sidings, which had been intended in the first instance to be placed at Ruddington, a few miles south of Nottingham, had showed both the up and the down sidings arranged so that the traffic could be worked right through from end to end in its proper direction, the land at Ruddington admitting of this being done without the necessity of constructing any very large earthworks. To meet the requirements of the traffic department, Annesley had been afterwards selected as a more convenient position for the sidings; but the natural fall of the ground towards the south at this place had prohibited the adoption of the arrangement originally intended, and the sidings as now laid down had been considered most suited to the altered situation. As the final quantities and accounts were not settled, it was impossible at the present time to give a definite analysis or statement of the cost of the works, arranged in such a way that the cost of the main line could be separated from the cost of the stations.

Sir DOUGLAS FOX, President, said that, as his son was not present that evening, he might be allowed to say a few words by way of reply. The question about side tips *versus* end tips had been one of very great interest in connection with that particular railway. The work was certainly entered upon with a prejudice against side tipping, and it was only allowed to be introduced with considerable caution; but he must say that, as far as he was concerned personally, he was a convert to the use of side tipping under such precautions as had been mentioned by Mr. Middleton and in connection with embankments of such very large size. Certainly the results obtained went to prove that, properly carried out, it did not lead to more slipping than took place in connection with end tipping. It was found, as Mr. Middleton had stated, that the speed at which the work could be executed was very greatly enhanced. It required however to be laid out on a proper principle. If it were carried out in a careless way it might produce great mischief, but as it was carried out by Messrs. Walter Scott and Company and the other contractors engaged in the work, he could only say that the results The President.

The President. had been quite satisfactory. With reference to the use of burnt clay for ballast, that was also a matter about which great hesitation was felt. One or two of the members had spoken that evening of the extensive use of that kind of material in India, with the practice in which country he was well acquainted; but they had not mentioned one particular factor which had to be dealt with in this country, and that was severe frost. He thought that, at any rate for ballasting purposes, burnt clay required to be used with very great caution, and to be thoroughly well burnt, which was not always an easy thing to secure: it should be burnt to a clinker as far as possible, and should be covered up, if possible, from the action of frost. Thus treated he thought it made very fair ballast where nothing better could be obtained. As far as possible on the Great Central Railway either slag, or, in some few cases near stations, granite had been used, but that was a luxury which the Company could not indulge in to a great extent. They had been obliged to use a certain amount of burnt clay, and had found it on the whole turn out satisfactorily. He was rather glad that Mr. Galbraith had made the remark with reference to the entrance into London. Perhaps Mr. Galbraith was not aware that that particular subject was coming before the Institution—probably next session—in the shape of another Paper, to be contributed by two members, in which the whole of the metropolitan arrangements in connection with the Great Central Railway were to be dealt with, the present Papers dealing only with the country portion of the railway. But he would like at once to tell the meeting that the question of the necessity of four lines into London had in no degree been lost sight of in all the arrangements that had been made. An endeavour had been made to secure a thoroughly good entrance into the terminus with seven lines of rails from Lord's Cricket Ground—where it was felt it was important to get all that possibly could be got while there was a chance. Beyond that at present there was only a 27-foot tunnel with a double line through to the Finchley Road, but the company had purchased the property for the additional two lines, and all the arrangements were made in connection with the tunnel, which was so constructed that the second tunnel could be easily and economically made alongside of it, the skew-backs of the central pier being arranged specially for that purpose. The matter had therefore not been lost sight of; and, at any rate as far as London was concerned, it had been not only foreseen but specially provided for. With reference to the question of curves, there was a 60-chain curve at Rugby, where it had been necessary

to put one in because the main line itself was on a curve, and in arranging for an island platform it was not possible to do with less than 60 chains. He thought the difference between this and an 80-chain curve could very well be detected if it was noticed while travelling in a fast train. There were few trains which did not stop at Rugby, but some ran through that station, and it would be found that the trains did not take the 60-chain curve as sweetly as the 80-chain curve. It was beautiful to see a fast train pass one of those island platforms round the reverse curve of 80 chains, with a proper tangent between the two curves. He would like to refer to the question of tangents between curves, because, although in this country it was thoroughly understood, foreign engineers often introduced great difficulties because they insisted upon too great a minimum length of tangent. He had had a case recently where it had been very important to lay out a line of railway round sharp spurs of mountains, and he had been bound by a law of the Medes and Persians, laid down by certain French engineers who exercised government control there, that very long tangents should be used between the reverse curves. That had made it impossible to lay out any line of an economical nature in passing round those spurs. Tangents were necessary, but without proper care they could be carried to too great a length. With regard to the permanent way, the extension to London had been laid with the company's standard permanent way. No special design had been made for it. On the question of concrete walls, referred to by his old friend Mr. Johnson and others, he quite agreed that it was of great importance, in building a wall of that kind, not to leave off at night with a smooth surface, but either to leave some of the plums exposed so that they might form a key to the next day's work, or to step it, as was mentioned by Mr. Robertson, and thus make quite sure that there would be no tendency in the work to slide on its base. He thought he had met, as far as he had been able in the time at his disposal, the main questions raised that evening, and he could only thank the members for the way they had received the two Papers. He hoped they would be able next session to hear the Paper describing all the terminal arrangements of the Great Central Railway in London.

The President.