Correspondence.

Mr. HAROLD BERRIDGE thought Mr. Dalrymple-Hay was to be congratulated on his clear account of an important work. Some details of the method of setting out the work might be useful to those engaged in similar undertakings. The mode described was devised by the Author, and the guide-rods mentioned were of his introduction. To line out the direction of the tunnel, two bob-lines (giving the centre line) were ranged by the theodolite, one close to the working face, and the other about 25 feet behind, which would suffice to guide the shield with accuracy for the same distance in front of the leading bob-line. It was advisable to keep a note of these bob-lines, giving their location and distance on the centre-line. They were hung from staples driven into the packing between the rings, and should be tied tightly to the staples, when a tap on the staple either side would adjust them with accuracy. The lines could be hung up on one side when not in use. They were sighted on to a board cut into the shield at its horizontal diameter, which could also be taken out when not in use for this purpose. This board should be as far forward in the shield as possible. When the shield ran on to a curve, the offsets, which should be calculated to $\frac{1}{8}$ inch for every foot in distance, were furnished to the foreman, together with a note of the distance of the leading bob-line behind or in front of the tangent point. It was then only necessary to measure the distance of the shield from the leading bob-line, add to or subtract from the tangent distance and find the required off-set, which should be the distance of the centre of the shield from the line given by the bob-lines. While the shield was being driven on the straight, it was evident that both sides must be driven forward equally. As soon as the shield started on a curve the edge of the shield on the outside of the curve must each time be driven forward of the inner edge by an amount equal to the difference in the lengths of the arcs of the inner and outer curves of the tunnel on plan, the length of the inner arc being equal to the length of one tunnel ring. The guide-rods Mr. Hay had introduced made this operation quite simple. The rods were made of 4-inch by 1-inch deal about 20 feet long, and ran in guides on the sides of the tunnel at its horizontal diameter. They were provided with hooks for attaching them to the shield, and could be Mr. Berridge.

Mr. Berridge. unhooked and run back out of the way when not wanted. When the bob-lines were put up, a line square to the centre line of the tunnel was put at the same time on the guides each side, by means of a special short-focus theodolite. As soon as the shield was ready to be driven forward, the rods were hooked on, and the ganger in charge, by watching them move over the marks on the guides, could keep his shield square by shutting off any ram inclined to lead. While on the straight both rods were graduated in natural scale feet and inches, but as soon as the shield reached the springing of a curve, the inside rod was changed for one graduated on a shrunk scale, that is to say, the distances representing feet and inches on the inner rod were to the natural scale on the outer rod as the length of the inner arc to the length of the outer arc; and consequently, by still apparently keeping his shield square the ganger gave it just the right amount of lead to take it round the curve. By using these rods in conjunction with the offset tables a shield could be as easily driven on the curve as on the straight, and even taken round a curve of 100 feet radius. The levels were given by boning-rods bolted to the tunnel roof about 1 foot below the soffit. They had cross-pieces which could be slid up and down and tightened with a thumbscrew when adjusted. An ordinary 14-inch level could read a staff 200 feet away with two or three candles, if the tunnel was fairly free from fog, but generally shorter distances were handier.

This system of setting out was accurate and expeditious, as by its means one man could do all setting out with lines and levels required for four faces, each putting six rings per day, besides subsidiary work in passages, etc.; all setting-out was done in meal times without interfering with work. In ranging long straight lines it was more reliable to turn 180° than to transit; both theodolite and level got badly out of adjustment in tunnel work, and needed frequent attention. The fog was also very annoying. Mr. Berridge had been unable to see a point only 300 feet away, even by aid of four 64-candle-power glow-lamps. The theodolite should have sliding plates to adjust over change-points, and was best set up on a 9-inch by 3-inch jack-plank supported at each end on, and wedged up tight to, the tunnel lining, with a good wide slot to let the plumb-bob through. Small tables, about 18 inches square, with angle-bar lugs, and wooden tops, were handiest to bolt on to the sides of the tunnel for using the level on. He had heard it suggested that shields should be made without tails, to enable them to be more easily guided vertically and horizontally. He thought it would be an advantage in this respect, but there would probably be trouble sometimes in getting in the iron after the shield had been driven forward. He certainly thought the smaller shields would be better with more rams at the bottom. A comparison of the 24-foot by 12-foot shields showed much more ram-power per foot of circumference in the larger than the smaller size. In some more recent tunnels there were sudden changes of gradient from 1 in 30 down to 1 in 120 up, and these required a good deal of negotiating with the present number of rams on the small shields. Mr. Berridge.

Mr. S. B. COTTRELL noticed that the steadiness of the lights on the trains was credited to the exceptional governing powers of the engines. This might be so in part, but he thought that this steadiness was largely due to the size of the conductor and the large section of the return rails; also to the fact that there could be comparatively few trains starting up at the same time and always on a down grade, as it was obvious that if there were any considerable drop on the line the efficiency would be proportionate to the number of trains being switched on and off. Mr. Cottrell would like to know the total drop on the line, with the maximum current. The lighting of the stations direct was a great improvement, and one that fully compensated for the outlay of capital. Mr. Cottrell.

In regard to the controller, he quite agreed with Mr. Jenkin that it was a complicated one, and questioned if any advantage could be obtained, even in the hands of a competent driver. He did not think that any advantage could be obtained from the cycle connections unless the driver was very careful, and his experience of drivers was that unless under constant observation, they exercised but little care. The introduction of a recording watt-meter, and a premium to drivers who kept schedule time with the least current, might tend to some improvement.

Mr. Cottrell thought that self-propelled carriages were most suitable for this style of traction: they had many advantages, such as avoiding terminal shunting, and by distributing the load the wear and tear of the road was reduced. If electric locomotives were adopted it would mean retaining a turnover locomotive at each terminus, and although an electric locomotive did not, like a steam engine, consume coal and water whilst standing, yet it would mean that about a third of the driver's time would be wasted. It was greatly to be regretted that the Board of Trade had spoilt the efficiency of the railway by the absurd restriction of speed round the 5-chain curve, as, with the experience gained on the Liverpool Overhead Railway, a speed of 30 miles an hour was perfectly safe.

Mr. Cottrell. Owing to the shortness of the sections at Liverpool, this speed was never attained in ordinary working practice, but it had frequently been done experimentally. If the restriction of speed was imposed because the Board of Trade thought that part of the cars were pushed and part of the cars pulled, it would be a very easy matter to arrange, by the insertion of resistances, that a larger proportion of the load should be pulled than pushed.

He had heard that at first there was an enormous cutting of the curved rails, and he might say that the same occurred at one time on the Liverpool Overhead Railway; in fact, at times it was really mysterious, as one day the right-hand curves would be reported as cutting, and the next day, perhaps, the left-hand curves would be similarly reported; but eventually, by careful inspection, the damage was brought home to two or three trains, and examination of them frequently showed that it was owing to the bogies having become slightly twisted. By stiffening all the bogies, careful attention to proper super-elevation and check-rails on curves, the cutting of rails had been entirely obviated.

The following figures from the Liverpool Overhead Railway might be of interest:—

Coal per unit generated	4·151 lbs.
Proportion of units used for driving trains, measured at the generating station, to the total units generated	80 per cent.
Units per train-mile	4·85
Average weight of an empty train	38 tons.
Number of seats in a train	134
Average speed of running, exclusive of stops	15 miles per hour.

The cost and calorific value of the coal used and given in the above was equal to 70 per cent. of best Welsh coal.

Mr. Crowell. Mr. FOSTER CROWELL thought that unusual praise should be given the Authors for the admirable way in which they had brought out the salient points of their subject. The most prominent, and doubtless the most important, feature common to both Papers was the matter of the curvature which was adopted. This was obviously a proper subject for criticism. To have adopted a larger minimum radius than was resorted to would undoubtedly have increased the cost of construction, and very probably have added to the difficulties encountered; but a very large increase in both would have been justified in order to prevent enormous curtailment in the earning power of the railway, amounting, according to the figures given by Mr. Jenkin, to upwards of 30 per cent. of an otherwise possible volume of traffic.

Mr. Crowell.

It would be easy to calculate how much additional capitalization of first cost, if necessary, would be justifiable in order to prevent such a loss in the operation of the line, and there would be additional minor advantages in the elimination of the sharper curvature. It was here assumed that there were no insuperable obstacles in the way of the adoption of a larger minimum radius. As to this Mr. Dalrymple-Hay was not explicit. Although he did state that it was necessary to introduce curves of 5 chains radius at certain points, he did not say that they could not have been avoided by a somewhat different treatment of the location problem, and inferentially, at least so far as the illustrations showed, the modification would have been practicable. This suggestion was not intended at all as a captious criticism, but was offered for the purpose of drawing attention to the paramount importance of designing and locating railways from the standpoint of their working, and not upon the basis of first cost of construction merely, important as the latter unquestionably was, especially in lines of the character under consideration. Another point Mr. Crowell would criticise was the adoption of the bull-headed pattern of rail for this tunnel, the difficulty and cost of electrically bonding such section being very much greater than was the case in the best modern practice in America, where flat-footed rails were exclusively used in which the copper bonds could be self-riveted and countersunk in the bottom flange out of the way of the joint-plates, and thus could be very much shorter—only a few inches instead of 3 feet 9 inches, as given by Mr. Jenkin; also, being made in U form, accuracy in spacing the bond-holes was not important, and being themselves riveted or upset directly to the rail, contact was insured. On other accounts the American type of rail was well adapted to meet difficulties of maintenance of permanent way incidental to tunnels, especially contracted ones. However, these were matters wherein local circumstances usually governed, and doubtless there were excellent reasons for adhering in this case to the London and South Western Company's standard pattern. The very perfect results accomplished in the tunnel-driving, underpinning, and other difficult underground work, as described in the Paper, must awaken warm admiration, and the skill displayed by those in charge of the work in overcoming the special difficulties encountered called for marked recognition. Particularly was this true in regard to the clever use of tempered clay to produce an artificial stratum about the shield, a distinct advance in the science of tunnelling in bad ground. The Author omitted a few details which seemed to Mr.

Mr. Crowell. Crowell to be worthy of mention. One was how the passing from the smaller to the larger section of the iron tunnel was worked out in the iron lining; whether a bell-mouth section was introduced, or a diaphragm, or a connecting-ring with deeper flanges. Also, when driving around the sharp curves, was the curvature introduced at each joint, or were several rings placed on the same chord? It was interesting and instructive to note that, notwithstanding the developments in tunnel-driving with metal shields as manifested in this work, to a certain extent the old and tried timbering methods were combined with them. It would seem nevertheless that the substitution of some form of metallic pilot or other form of advance appliance, such as had already been used in apparently less favourable localities, might have found a good application in this case; and as the point was very interesting and important, the writer hoped that the Author, in replying to the general discussion, would enlarge somewhat upon the question. The writer would also like to inquire, in regard to the matter of ventilation of the running tunnels, whether any trouble had been experienced by the passengers in the cars from rarefaction of the air due to the movement of the train.

Mr. Cruttwell. Mr. E. CRUTTWELL thought that some particulars of the life or durability of cast-iron subways might be of interest, as there was an impression current that a thickness of an inch or so of cast iron could not last very long, and that some day these subways might burst in. He believed, however, from observations made at the Tower Subway, that this was not likely to occur. The Tower Subway, which crossed the Thames between the Tower Bridge and London Bridge, was built by Messrs. Barlow and Greathead in 1869 with cast-iron segments and lime grout forced under pressure round the outside, much on the same system as the Waterloo and City Subway. When the Tower Bridge was opened in 1894 most of the traffic was diverted from the Tower Subway, and the Corporation of London, who built the bridge, were obliged to compensate the Subway Company. In order to ascertain its state of preservation and consequent value, pieces were cut out of the subway in the worst-looking places where water was dripping through the joints, and the lime was found adhering to these in a perfect state of preservation. On knocking off the lime the tar coating on the outside of the cast iron was also found to be perfect. This examination was made in 1896, or 27 years after the subway was constructed. Mr. Cruttwell therefore thought that if the interiors of the subways were properly looked after, and provided the soil contained no corrosive ingredients, there need be no apprehension about the exteriors, at any rate, for many years to come. Mr. Cruttwell

Mr. A. BROMLEY HOLMES suggested, in reference to the load-factor of only $33\frac{1}{2}$ per cent. and the relatively high expenditure of coal per unit generated, viz., $8\frac{1}{2}$ lbs. (Appendix, p. 95), that a great improvement could be effected by the addition of a battery of accumulators worked in parallel with the generating plant. The power for the first section of the Liverpool Electric Tramways, with forty-five double-decked fifty-passenger cars in service, was temporarily supplied with electrical energy from one of the lighting stations of the Corporation, in which high-speed direct-coupled plant was employed somewhat similar in size to that in use on the Waterloo and City Railway. Three engines were required to meet the requirements of the service, each capable of giving an output of 300 amperes at 550 volts. The current required by the line varied from 100 amperes to 900 amperes, under which circumstances the engines had naturally to work under unfavourable conditions. By the addition of a battery of accumulators capable of giving a discharge up to 400 amperes, it was found possible to carry out the work by the use of only two engines running on an almost steady load of about three-quarters of their rated power, as was borne out by the charge and discharge of the battery as registered by a recording ammeter. The two engines, if run at full load, would give an output during the 18 hours of 5,760 Board of Trade units, and the actual amount of current metered to line was 4,409 units, giving a load-factor of approximately 75 per cent. The capital cost of the battery of accumulators was less than that of an additional set of plant, but the expenses of maintenance would of course be somewhat greater. This additional maintenance charge was more than counterbalanced by the possibility of running the engines at a continuous steady load. Mr. Holmes.

Mr. E. S. W. MOORE thought it would be interesting if Mr. Jenkin would give the dead weight upon the tread of the motor wheels, and say whether any wear had been noticed at the rail-joints. He had referred to the motor suspension springs, but from the drawings Mr. Moore understood the function of these springs was to give some "elasticity" to the motor torque, and that the whole of the weight of the magnets and armature was without spring-support proper. In Mr. T. Parker's Paper on the Electrical Equipment of the Liverpool Overhead Railway,[1] it would be noticed that the motor-magnets there had a sort of "com- Mr. Moore.

[1] Minutes of Proceedings Inst. C.E., vol. cxvii. p. 71

Mr. Moore. promised" spring support, *i.e.*, in the normal position of the armature axle in the horns of the truck frame the whole of the magnet weight was spring-supported, and above and below the normal position there was a varying downward or upward pressure direct to the axle at the motor-bearings. In view of the controversy on geared *v.* gearless motors for railway work and of the large capacity of the motors here employed, the question was of some importance.

Mr. Dalrymple-Hay. Mr. Dalrymple-Hay, in reply to the Correspondence, said Mr. Berridge had described the methods adopted by the Author for setting out the centre lines underground, and the apparatus devised by him for guiding the shields and checking the work generally, but a more detailed illustrated account of this had already appeared.[1] The system, as Mr. Berridge remarked, was both accurate and expeditious, and had since been adopted on the City and South London Railway (Moorgate Street extension), a portion of the Central London Railway, and the Baker Street and Waterloo Railway now under construction. With regard to the proposal to use a shield without a tail to overlap the lining, Mr. Dalrymple-Hay suggested this type of apparatus to the late Mr. Greathead some years ago for the shields of the London tunnels which were wholly in the clay; not because it would be easier to guide the shield, but because the iron lining could then be built directly upon the solid clay without the intervention of soft grout below it, which undoubtedly was one of the several causes which, taken together, were, in Mr. Dalrymple-Hay's opinion, responsible for subsidence of the ground. By this means the thickness of the grout could be made as small as possible, thus reducing the cost of the work and the time occupied in grouting.

The secret of successful tunnel-driving lay in the means adopted to guide the shield and maintain the plane of the leading ring parallel to that of the cutting edge of the shield. If this were attended to, but little difficulty would be experienced in erecting the lining. Mr. Crowell's questions as to the reasons for adopting 5-chain curves had been answered by Mr. Galbraith. The reasons for adopting the bull-headed permanent way were:—First, the South Western Company had to work and maintain the line, and, as their standard type could be introduced without unduly affecting the size of the cars, it was advisable to have uniformity of pattern on that account. Secondly, a chair road spiked to a continuous longitudinal admitted of the most substantial mode of securing

[1] *Railway World*, 6 July, 1897

Mr. Dalrymple-Hay.

the check rail in position on curves, and the check could be very easily renewed and at minimum cost. Thirdly, the rails, being narrow and deep, admitted of being easily bent to sharp curves, which was not the case with the "bridge" and Vignoles sections. This was of some importance in regard to cost of renewals and maintenance, after the recent experience of the difficulties of bending the heavy bridge-pattern rails of the Central London Railway, where special apparatus had to be devised for that purpose.

The method of passing from the smaller to the larger section of the iron tunnels consisted of "breaking up" from the small tunnel to the level of the top of the large one to be constructed, and there driving a heading about 12 feet long. Two crown bars were then put up to support the head trees, and, as the side trees were taken down the heading was gradually widened out on each side until a timbered "length" had been formed. An ordinary brick-lined tunnel was then constructed within the "length," and formed the shield chamber from which the large tunnel was subsequently driven. All the bars were built in, and of the three shield chambers constructed two were of brick and one of cast iron. One of the brick chambers had pitch-pine bars, the other steel joists 8 inches by 6 inches placed about 2 feet apart. The brick chambers were 28 feet 9 inches horizontal by 26 feet 9 inches vertical diameter, the brickwork in the arch being 2 feet 7½ inches thick. The cast-iron chamber was circular in section, 28 feet internal diameter, with flanges 12 inches deep, the bars being steel joists 8 inches by 6 inches. This latter type of chamber possessed many advantages, and was quicker, safer, and cheaper to construct than the brick chamber, and had since been adopted elsewhere. The ordinary parallel castings for the straight portions of the line were used on all curves other than those of 5 chains radius by introducing variable thicknesses of wood packing between the circumferential joints of adjacent rings. The exact thickness of the packings depended not only on the curvature of the line, but also on the accuracy with which the shield was driven, and the care with which the lining was erected. On 5-chain curves special radial castings were used, but owing to the practical difficulties of driving the shields correctly to line and level, packings of variable thicknesses were put in from time to time. On the straight portions of the line also it was absolutely necessary to use variable packing to adjust the lining as required. Space did not allow Mr. Dalrymple-Hay to reply fully to Mr. Crowell's request that he should enlarge upon the question whether it would be advisable or otherwise to substitute for the timbering system of tunnelling some form of metallic pilot in advance of the shield. Speaking broadly, Mr

Mr. Dalrymple-Hay. Dalrymple-Hay was of opinion that it was generally better to make a shield in one piece than to have two machines working, one in advance of the other, at any rate, in water-bearing materials, where air losses were of so much importance, and it was advisable to avoid subsidence of the ground. No trouble had been experienced by passengers in the cars from rarefaction of the air due to the movement of the train. Mr. Dalrymple-Hay corroborated Mr. Cruttwell's statement as to the excellent state of preservation of the cast iron of the Tower subway, as at the time the experiments were made, the late Mr. Greathead showed him a piece that had been drilled out of the skin of the subway, and, although it had been in position 27 years, it smelled strongly of tar and was in every way absolutely perfect.

Mr. Jenkin. Mr. BERNARD M. JENKIN, in reply to the Correspondence, said that the total weight on the four driving-wheels of an empty motor-car was about $17\frac{3}{4}$ tons, which was increased to about $21\frac{1}{2}$ tons when the car was loaded, making the load on each driving-wheel about $5\frac{3}{8}$ tons. The whole weight of the motor was taken by the axle. The springs were only to prevent the magnets rotating. He was very glad that Mr. Cottrell was able to say, from actual experience on the Liverpool Overhead Railway, that 30 miles an hour was a perfectly safe speed on a 5-chain curve. There were, he believed, several curves of 4 chains on that line, and he hoped that the results obtained on them would induce the Board of Trade to modify the limit of speed in the case of the Waterloo and City Railway. What Mr. Cottrell had said as to the cutting of the rails was extremely interesting, and Mr. Jenkin believed that want of truth in the bogie-frames would be found to be the real cause of the cutting of the rails on the Waterloo and City line also. The bogie-frames were certainly not stiff enough at first, and had been altered as occasion permitted. There had as yet not been sufficient time to see the result, but if it prevented the axles getting out of parallel it was certain to improve matters, and he hoped might entirely remedy them, as had been the case at Liverpool. The figures given by Mr. Cottrell were of great interest, and would enable further comparisons to be made in the working of different lines.

---

21 and 28 November, 1899.

SIR DOUGLAS FOX, President,
in the Chair.

The Discussion upon the Papers on the Waterloo and City Railway and its Electrical Equipment occupied these evenings.