Correspondence.

Mr. A. P. Boller, of New York, had read with keen interest the account of the construction of the Detroit Tunnel, one of the most important transportation problems in the United States. Having been concerned with the prolonged investigations which had had in view a bridge crossing of the Detroit River, he considered that the tunnel solution, with the approach and terminal question involved, was the correct one from all points of view, the efficiency of electric traction in trunk-line service having been established. The design of the tunnel adopted formed a radical departure from established shield methods, and it was certainly novel in conception. When the Author first proposed his design, Mr. Boller discussed with him the practicability of its execution; he then saw no reason why it should not be a feasible proposition, and he so advised the Author. The clay bottom of the Detroit River was of admirable consistency for the application of the design proposed, and the river not being a silt-bearing stream, there was little or no probability of any river-deposit dropping into the great trenches which had to be dredged and kept open during comparatively long-continued concreting operations. Tremie methods of depositing concrete under water had long been established as giving satisfactory results in quiet water, and this had been fully borne out by the tests on the sample cubes which had been taken out of the actual work. As to the wisdom of adopting this novel tunnel construction in preference to long-established methods, it had been wholly a question of cost, time, and gradients, but the figures given appeared to vindicate the plan adopted. The Detroit Tunnel cost of 90 cents (3*s.* 8*d.*) per cubic foot seemed low, and while accurate costs could be computed on the basis of materials and labour, it was difficult for an inspector to obtain particulars of all the labour and incidental costs that a contractor paid out to make up the grand total. Nevertheless, the difference in cost between a shield-driven tunnel in rapidly penetrated silt at $1·65 per cubic foot and the Detroit system even at $1 was remarkably great. As to the shallower level at which the Detroit system had permitted the tunnel to be built, involving as it did the very important question of the gradient and length of the approaches, the Detroit system in a bottom adapted to it, appeared to have an advantage over the shield system. While it was true the level of a shield tunnel could be raised by blanketing the river-bottom on the tunnel-line to hold Mr. Boller.

Mr. Boller. the air during driving, this involved a mound of material over the tunnel-roof and sides that might interfere seriously with river-flow or navigation. As to time, 3 years had been taken to complete the aqueous portion of the Detroit Tunnel, which, in his opinion, could certainly have been done by the shield system in two-thirds of that time. On the whole, the Detroit system of tunnelling for that crossing, under all the conditions of the problem, had been boldly and wisely conceived, and skilfully carried out; and the Author was to be congratulated on the successful accomplishment of a very novel undertaking, as well as on the admirable Paper in which he had recorded the particulars of this great work.

Mr. Carson. Mr. H. A. Carson referring to foreshadowings of the Detroit work, pointed out that in 1845 De la Haye, of England, suggested making submarine railways by constructing wrought-iron tubes above water, and then sinking them to a suitable bed. In 1869 Martin and le Gay, of France, proposed a tunnel, between France and England, consisting of metal tubes sunk to the bed of the Channel and surrounded by concrete. The Martin–le Gay scheme provided also for outer frames attached to the tubes, and for boarding to prevent too great a lateral spread of concrete. These early projects were schemes merely. He did not know of any actual construction that followed De la Haye's suggestion until Mr. Belgrand, in 1866, made a pair of small pipe-tunnels for sewers under the Seine in Paris. Each had a diameter of 1 metre (40 inches), was 156 metres (510 feet) long, and was made of iron plate. Since then there had been numerous examples of sunken iron water-pipes. The first masonry tunnel of the De la Haye class, and also the first of this kind large enough for men to walk through erect, was believed to have been made by Mr. Carson himself, assisted by Messrs. W. Blanchard and F. B. Smith, when, in 1893–94, he built the Metropolitan sewer in the outer portion of Boston harbour.[1] Those tube sections laid in 1893 were of brick, with exterior skins of iron plate, had external diameters of a little over 8 feet, and were 50 to 65 feet in length; temporary watertight bulkheads were inserted at each end, and external flanges for bolting contiguous sections end-to-end were provided. These bulkheaded sections were tested for airtightness, and inferentially for watertightness, by exhausting air from within and measuring the degree of rarefaction with a vacuum-gauge. The weight of the sections relatively to their displacement was such that they would barely float in sea-water. They were made on the upper portion of a sloping beach and, when completed,

[1] Described in the Annual Reports of the Metropolitan Sewerage Commissioners of Massachusetts for 1893 and 1894.

were moved down the beach on rollers and timbers to where the incoming tide would nearly cover them with water. Each section was towed at high tide, by floating cranes, to a suitable position above a trench dredged in the gravel bed of the harbour. A section was then lowered, by admitting sufficient water, to nearly its final position, saddles to receive it being accurately placed in the bottom of the trench. When a contiguous section had been laid a few inches from its predecessor, the two were bolted together end-to-end by divers. A rubber gasket was provided at each end between the flanges. The subsequent operations were the backfilling of the trench around and over the pipes, the successive removal of the bulkheads, beginning at the land sections, and the pumping out of the water. At each joint between two consecutive sections, a short closing length of masonry had to be put in, joining the interior adjacent brick walls. This was accomplished without difficulty, as the outside gaskets had made the joints perfectly watertight. As the rubber gaskets were outside the masonry, the fact that they would become disintegrated in time was not a matter of consequence. In progressing with the work next season a rather different method was adopted, the tube sections, weighing 100 tons each, being made in cradles above water, alongside of a wharf. After completion and bulkheading they were lowered by long vertical screws moved by steam-power. The sections were then towed ½ to ¾ mile to their positions for lowering—also on to saddles placed in the dredged trench. These later sections had a skin of wood 4 inches thick, inside of which was a 6-inch thickness of Portland-cement concrete, and an interior ring of brickwork 8 inches thick. It was found that all the tunnel was perfectly watertight at the joints and elsewhere, true to line and level, and satisfactory in every way. When Mr. Carson became a member of the Advisory Board of the Detroit tunnel, he naturally proposed a similar method, referred to on p. 10 as method B. He thought that the joints, although larger, would be as tight at Detroit as at Boston, and that the strength could be made as great as might be desired. He did not propose an outer surrounding volume of concrete, on account of its expense. It must be admitted, however, that a large expense was justifiable in protecting a tunnel whose top was brought up to the very bottom of a river with such an enormous floating traffic. The possibility of a foundered vessel resting on the top of the tunnel had never been lost sight of by the Advisory Board. The scheme proposed by the Author for Detroit was not merely a re-invention of that of Martin and le Gay; it possessed in addition thick inside walls and other important features. Mr. Carson.

Mr. Carson. In 1877 William Sooy-Smith, an American engineer, proposed to tunnel under the river at Detroit by sinking pneumatic caissons such as were used in making piers. These caissons were to touch one another end-to-end under the river, and in them the tunnel was to be built. It was an interesting fact that the general features of the French scheme of Martin and le Gay had been recently used at Detroit at the very same time that the American plan of Sooy-Smith was being used in Paris, in connection with the crossing under the Seine of the Metropolitan subway. Each scheme had been re-invented with important modifications.

Mr. Dawson. Mr. PHILIP DAWSON had read with great interest the very able Paper which Mr. Wilgus had prepared, and wished to make a few remarks in connection with the electrical equipment of the tunnel and its approaches. It was obvious that in the present case the only point for consideration had been the system of electric traction that would be the most suitable for a short section of line, of which—as far as could be gathered—there was no likelihood in the near future of any extension. Further, the line was all in a tunnel which, from an economical point of view, it was advantageous to keep to the smallest possible dimensions. Under these circumstances the choice of the continuous-current system finally selected seemed to be fully justified. At the same time he felt obliged to take issue with the Author on his very general statement that "direct current was respectively 12 per cent. and 32 per cent. less expensive in first cost than the three-phase and single-phase systems, and 4 per cent. and 20 per cent. less expensive annually." The conditions laid down in the specification, on which the tenders for the various systems had had to be based, were not stated, nor were the reasons for stating the additional annual cost; without such particulars it was impossible to offer any detailed criticism. All he could say was that the Sarnia tunnel had been equipped with the single-phase system and appeared to be working satisfactorily. He knew that, at the commencement, the New York, New Haven and Hartford Railroad had a great deal of trouble with the single-phase system which they installed—trouble which, he ventured to think, might have been avoided. They seemed, however, quite satisfied with their present results, as was proved by the extensions of the single-phase system which they proposed to carry out shortly. The success of single-phase current for general electrification had been proved without a doubt on the Continent of Europe, and all the principal railway-authorities of France, Switzerland, Austria and Sweden, and also on the various German State railways, had, after the most careful investigation, unanimously decided in favour

Mr. Dawson.

of the single-phase system; they considered it the only possible solution when the electrification of an existing railway that included urban, suburban, and interurban sections had to be carried out. The results obtained by Mr. Dawson on the London, Brighton and South Coast Railway were entirely opposed to the statements made by the Author as regarded the comparative results of the various electric-traction systems; and further, many well-known American engineers did not agree with the Author's views as to the merits of the various systems. Thus, Mr. George Westinghouse, in a Paper read last year before the Institution of Mechanical Engineers in London, had been all in favour of the single-phase system considered from every point of view. Mr. Dawson also disagreed altogether with the opinion expressed by the Author that the continuous-current system presented elements of greater reliability than the single-phase system. He did not claim that the former was not reliable, but he emphatically claimed, as the result of over 2 years' operation (including experimental running) on the Brighton Railway, that the single-phase system was, at least, quite as reliable as any continuous-current system.

Mr. Jacobs.

Mr. C. M. Jacobs congratulated the Author on his excellent description of the first important trench-built tunnel that had been brought to a successful conclusion. When, however, he made certain general assertions, such as that on p. 27, where he expressed the belief that "the subaqueous method used at Detroit may be utilized with marked reduction of cost and hazard in many locations where the employment of shields and compressed air has hitherto been considered obligatory," there was room for some question whether the shield and compressed-air method—if applied to the conditions described by the Author—would not have resulted in economy of either time or money, or both. This was not to be taken to imply that the methods employed at Detroit might not point to a useful method of tunnelling in certain other conditions, e.g., where suitable ground existed with so great a depth of water that the air-pressure in the working-chamber would exceed that at which it would be feasible for men to work. Before discussing this phase it might be questioned whether, in his "History of River-Crossing Projects" the Author had not been misinformed on one detail. He said:—

"Work was *permanently suspended in the latter part of 1872, owing to* continued inrushes of water and gas and loss of life. Ordinary tunnelling methods with timber lining were employed, as the use of shields and compressed air was deemed inadvisable at such great depths and in such small drifts."

Probably the fact that the modern combination of shield and

Mr. Jacobs. compressed air was still untried and unknown at that date, might also have had something to do with this decision. It was true that a tunnel-shield and lining were described by Brunel in a patent specification in the year 1818, and that a shield was used by him in the original Thames tunnel from 1825 to 1828, and again from 1835 to 1843. The next tunnel driven by the shield method was in 1869, when the London Tower subway was built. In 1870 Mr. Beach drove his Broadway tunnel in New York City, and in 1872 short pieces of tunnel were driven by shield at Cincinnati and Cleveland, Ohio. All these tunnels were driven without the use of compressed air as a means of supporting the ground. In 1830 Cochrane took out his patent for the use of compressed air for expelling the water from water-bearing ground during the excavation of shafts and tunnels, in the manner in which it was used at the present day. The system was first used in 1839 in a French coal-mine shaft. The first tunnels driven by the use of compressed air were constructed in 1879, simultaneously at New York City and at Antwerp. In both these cases no shield was used. The first time the shield method was combined with compressed air in the tunnel was in the case of the City and South London Railway in 1886. This point was of no real importance except in an historical sense, and unless the records showed that in 1872 actual discussion as to the use of shield and compressed air had occurred, it was difficult to understand how such a method could have been considered inadvisable at that time, as it certainly was unprecedented.

To turn to the Author's contention that in this particular case the trench method adopted was superior to the shield method, he stated that the former method was adopted because the latter was considered too hazardous and expensive, owing to the very small depth —about 3 or 4 feet—of cover, and also because the lowest tender on the trench system was $2,000,000 less than the one on the shield system. It must be confessed that this latter reason was a fairly conclusive one, and yet it might be possible to show that these tenders were based on misapprehension, especially due to the odium and fear which seemed to attach to the idea of using compressed air, which nevertheless in moderate pressures—say, up to 30 lbs. per square inch—was not at all a thing to be alarmed at, in the light of present-day knowledge and with proper medical provision. It would be noticed that in this case the pressure due to the whole hydrostatic head would almost certainly not have been needed, and 25 lbs. per square inch would have sufficed. It was therefore possible that these tenders did not afford any solid grounds for believing that the trench method was necessarily superior to the shield method in this particular case. The depth of water at the place where the cover became so small appeared from Fig. 4, Plate 1, to be about 41 feet. As the draught of the lake vessels using this waterway was only about 19 feet, it would seem that there would have been nothing to prevent the placing of a clay blanket over the tunnel had the latter been driven by compressed air, and had the natural cover not been strong enough to prevent blows. It might be remembered that the Hudson River tunnels of the Hudson and Manhattan Railroad, in New York, were within 5 feet of the river-bed in some places, the material there being a soft mud much less strong than the tenacious clay of the Detroit River; and to turn to examples nearer home, the Blackwall tunnel across the Thames came within 5 feet of the river-bed, and in open gravel and ballast at that. It was useless to labour the question of the practicability of applying the shield method here, as to anyone conversant with this type of construction it was obvious, and it only remained to consider whether the shield and compressed-air system or that used would have been the more economical of time or money. This was altogether apart from the fact that by the use of the shield there would have been no interruption to the heavy shipping traffic using this waterway, and that the work would have been entirely independent of any delays due to severe winter weather. It would seem that even the Author's own figures decided in favour of the shield as regarded economy. It would be noticed that after the first method of driving the approach-tunnels had proved a failure, a second method was adopted, in which a middle drift was first put through, the centre wall being built, and the section then completed by driving side shields under compressed air. It would be readily admitted by anyone conversant with tunnel work how much more expensive it was to build a tunnel in several operations than by two separate tubes in one operation. The chief expense with the latter was the cost of the iron lining, which was offset by the delay and expense of the other piecemeal method. As it was, the cost of the approach-tunnels was stated to have been $228 per lineal foot of single bore built in normal air, and $257 built in compressed air, while the trench-built tunnel under the river had cost $332 per lineal foot of single bore. It thus appeared that the under-river portion exceeded the approach-tunnels (expensively built as the latter were) by $75 per lineal foot of single bore, or $150 (£30) of double bore. As there was about 2,600 feet of under-river work, this amounted to $390,000 (£78,000), which was probably five times as much as the provision of a clay blanket would have cost. In case it might be feared that Mr. Jacobs.

Mr. Jacobs. the river-current would sweep away the blanket, he might state that on the East River tunnels of the Pennsylvania Railroad at New York City, the blanket had been successfully used in a current of $4\frac{1}{2}$ miles per hour, whereas at Detroit the maximum was stated to be 2·29 miles. The velocity of the ebb-current in the North or Hudson River, in which also clay blankets had been used, was about 3·22 miles per hour in a low-river season. This current-velocity would be increased by an increase in river-discharge. Some detailed estimates of the time and money required to build these tunnels by the compressed-air and shield method might be presented for the purpose of comparison with those actually incurred. They were based on the use of two shields on each side of the river, so that advance could be made simultaneously from both shores. The average rate of progress, in the compact "silt" under the land, of the 23-foot diameter shields of the North River tunnels of the Pennsylvania Railroad was 225 feet per month. This material was the nearest approach to the Detroit clay which these shields experienced. In the silt under the river, in which an average of 33 per cent. of the total displaced material was brought into the shield, progress had been delayed by a good deal of experimental work, but the average rate had reached 405 feet per month. The old St. Clair tunnel, 21 feet 6 inches in external diameter, which seemed to have been driven through ground closely resembling that found at Detroit, and in fact crossed this same river about 57 miles north of the tunnel described in the Paper, achieved an average rate of advance of 207 feet per month in normal air and 263 feet per month in compressed air, a maximum advance of 308 feet being made in one month. This tunnel was built in 1888, comparatively early in the history of tunnel-shields, and was, in fact, the most ambitious of any attempted up to that time. It was reasonable to expect that at Detroit the shields would make an average progress of 250 to 300 feet per month per shield. Each shield would have 4,155 feet to travel, namely, half the total distance of 8,310 feet from portal to portal. At the rate of 250 feet per month, this distance would be covered in $16\frac{3}{4}$ months, and at 300 feet per month in $13\frac{3}{4}$ months. On the North River tunnels of the Pennsylvania Railroad into New York City, the putting in of the concrete inner lining (delayed by a considerable amount of steel-rod reinforcement) took 7 months for the total length of 12,200 feet of single tunnel. At the same rate of progress the 16,620 feet of the Detroit tunnel would have taken, say, 10 months. The total time, therefore, on the basis of progress at the rate of 250 feet per month would be $26\frac{3}{4}$ months, or, allowing 10 per cent. for unexpected delays,

$29\frac{1}{2}$ months; and, on the assumption of 300 feet per month, this time would be reduced to $26\frac{1}{4}$ months. As far as could be gathered from the Paper, a period of not less than 42 months had elapsed between the time of breaking ground and finishing the concrete lining. A considerable saving of time for the shield method was, therefore, indicated, even on the basis of using only four shields and driving from each portal. It would be a question of economy whether it would pay to install additional shields and drive the approach- and river-tunnels simultaneously from intermediate shafts, thus approximately halving the time required to drive and line the tunnels. Mr. Jacobs.

As to the cost, taking the basis of using two plants and driving the tunnels simultaneously from each portal, with tunnels 23 feet in external diameter, and allowing for the cost and depreciation of plant, engineering, provision of a clay blanket, and all field and administrative charges, but exclusive of contractor's profit, Mr. Jacobs had no hesitation in stating (and this statement was based on two distinct experiences) that the work could have been comfortably carried out for \$4,100,000 to \$4,155,000 (£820,000 to £831,000), that was, \$246·67 to \$250·00 (£49 6*s.* 8*d.* to £50) per lineal foot, including a very liberal allowance for the clay blanket. The actual cost seemed to have been about \$4,544,912, made up as follows:—

Western approach . .	4,264 feet	at \$227·71	per foot =	\$970,965
Subaqueous work . .	5,334 ,,	,, \$332·29	,, ,, =	\$1,772,444
Eastern approach . .	7,022 ,,	,, \$256·55	,, ,, =	\$1,801,503
Total . .	16,620 ,,	,, \$273·00	,, ,, =	\$4,544,912

In this connection attention must be directed to the Author's comparative statement of the costs of various subaqueous tunnels. These were grouped and stated in such a way as not only to be of "little precise value," as stated in the Paper, but to be actually—though unintentionally so—misleading to a serious degree. For example, the Detroit tunnel had cost \$1·057 per cubic foot and \$332 per lineal foot in the under-river portion, while the old St. Clair tunnels cost \$1·08 per cubic foot and \$333 per lineal foot for the whole length from portal to portal. In the latter case compressed air was not put on until the shields entered the river section, so that the portions corresponding with the approach-tunnels in the former, namely, 1,994 feet on the Canadian side and 1,716 feet on the American, or a total of 3,710 feet, were driven in normal air, against 2,460 feet driven with the aid of compressed air.

Mr. Jacobs. Nearly all the difficulties experienced on the St. Clair work were met with in the normal-air sections, and the ground flowed in through the shields to such an extent that frequently 50 per cent. more ground was taken in than the cubical content of the finished work. It was therefore fair to suppose that, had compressed air been used in the approaches, an appreciably lower cost would have been recorded, though, even so, this old tunnel, built 20 years ago, with every appliance so much less developed than at present, cost only \$0·02 per cubic foot more than the subaqueous portion of the Author's tunnel. Another example which needed serious qualification was that of the North River tunnels in New York City, quoted as costing \$1·65 per cubic foot and \$300 per lineal foot. These figures referred to the tunnels of the Hudson and Manhattan Railroad, and were given, without any qualification, as being in silt. As a matter of fact, this cost was the average for tunnelling both under the river and on land, where the face consisted often of part rock and part silt, which was a particularly difficult and dangerous combination; and it also included very heavy expenses due to heavy buildings in a congested section of the city having to be cared for. Where the tunnel was in the true silt, without admixture of other materials, the cost was \$144 per lineal foot, or \$0·79 per cubic foot of internal bore, and this figure could be reduced, with the knowledge and experience now gained, to about \$130 per lineal foot, or \$0·72 per cubic foot. To take another example, and one not cited by the Author, the Pennsylvania Railroad had recently built two tunnels of 23 feet external diameter, heavily lined with cast iron and concrete, across the Hudson River at New York City. The cost of this work had been much enhanced by a large amount of testing and experimental work in connection with the original design to place pile foundations under the tunnels to support the heavy main-line traffic which they had to sustain in the soft river-bed. These tests and experiments occupied about 18 months, and many expensive details were embodied in the design, which delayed the work greatly. Very careful cost-records had been kept during the carrying out of the work, and these showed that with the experimental features and experimental delays eliminated, the cost of these tunnels had been \$256 per lineal foot, or \$1·04 per cubic foot of internal bore as driven from both sides of the river. Had the tunnels been driven from one side only, as would have been done had no piles been contemplated, the cost would have been reduced to \$245 per lineal foot, or \$1 per cubic foot, of internal bore; and the tunnels would even then have been finished in plenty of time to be completed simultaneously with other parts of the system. Of course all this kind of direct comparison between results obtained under totally different conditions, was bound to be misleading and was of very little use; but, if it were used at all, care should be taken to see that the conditions which did obtain in each case were correctly stated. Mr. Jacobs.

With regard to the dryness of the completed structure, the Author stated that the leakage was equivalent to 0·85 gallon per 24 hours per lineal foot of single bore. These tunnels were wholly in clay. The shield-driven North River tunnels of the Pennsylvania Railroad were not only in silt, but in gravel (heavily charged with water), sand, and rock—all well below tide-level. The total length of single bore of shield-driven tunnel was 12,196 feet, and the leakage averaged 0·0544 gallon per lineal foot of single tube per 24 hours. It would thus be seen that the leakage into the Detroit tunnel (which leakage, however, was stated to be diminishing and on the way to stopping) was at the date of the Author's writing seventeen times as much as in the shield-driven Pennsylvania-Railroad tunnels. In conclusion, it would seem that the methods used at Detroit displayed greater pains to be original rather than to follow certain well-trodden paths which Mr. Jacobs had no doubt would have quite probably led to the quicker and cheaper accomplishment of the required result. That the Author and all those in charge of the work had every reason to be proud of it and deserved the thanks and congratulations of the profession for a useful, instructive, and successful experiment, was undoubted; but sweeping assertions as to the superiority of the method adopted over others—even in this particular case where every condition was in its favour, and still more so as a general proposition—needed to be very carefully qualified before they could or should be accepted.

Mr. M. E. KERNOT had seen the question of tunnel versus bridge for crossing rivers and estuaries frequently raised in various parts of the world, and he thought the Author's work at Detroit had done much to support tunnel schemes. Another much debated point, the question between two single-track tunnels, or one large tunnel for a double railway-track, was decided in favour of the twin tunnel, and this agreed with the result of his own investigations. The saving of fall and rise, and the consequent saving in the length and cost of approaches, by keeping a subaqueous tunnel up to the limit of depth required for navigation, had also been demonstrated. The calling for tenders on a general specification, with designs which tenderers had liberty to modify or depart from, possessed great Mr. Kernot.

Mr. Kernot. advantages for works of unusual character, and appeared to have led to good results in this case. It would have been interesting if some particulars had been supplied as to how the sides of the open cuts were supported while the heavy retaining-walls were being built, as the clay, which required a slope of 1½ to 1 for the slopes above those walls, had to be undercut when the walls were put in. No reason was given for the adoption of different designs for the retaining-walls in the western and eastern open cuts. The walls were shown with different cross-sections, and the concrete had been reinforced in one case and not in the other. The difficulties met with in execution appeared to have been greater in the approach-tunnels than in the sub-aqueous tunnel, as the latter, though costing more per unit of length on account of the steelwork, seemed to have given little trouble, while in the case of the approach-tunnels changes of working-method became necessary while they were in progress. With regard to the subaqueous tunnel, it was stated on p. 23 that for a distance of 1,000 feet in mid-channel the tremies were used for prodding holes in the clay to the underlying hard stratum, and for filling these holes with concrete, thus apparently giving solid support to the tunnel; but at the bottom of the same page it was mentioned that there had been a gradual settlement of this section. This suggested that the tremies had not been effective in reaching a sound foundation, and that they should not be much relied on for such work. The thickness of concrete used for the subaqueous tunnel appeared to be large. At Chicago the tubular method was being used in the construction of the La Salle Street tunnel, which had 27 feet of water over it, and a thickness of 2 feet of special waterproof concrete inside the steel tube was considered sufficient; while at Detroit, with 41 feet 9 inches depth of water, the total thickness of concrete was about 6 feet on top and 4 feet 6 inches on the buried sides. The reason given for not adopting the tubular or "pipe" method of construction (Method B, p. 10) was the difficulty of making the joints below water, but this objection would have been met by tubes with ends made with diaphragms and casing exactly as used by the Author. And it should be noted in this connection that at Chicago it was considered practicable to do most of the concrete lining in the tubes before they were sunk, thus largely reducing the cost of that part of the work. The whole scheme bore the impress of a bold conception, with highly intelligent and masterful execution, and the Author and his co-workers deserved congratulations on their success, which marked a notable step forward in subaqueous tunnelling. Mr. Kernot, who was President of a recent Royal Commission on the question of traffic-connections across Sydney Harbour, found that the recommendation of that Commission for the abandonment of a bridge scheme in favour of separate subaqueous tunnels for railway, tramway and vehicular road-traffic, in situations which were in many respects similar to those at Detroit, had been supported and strengthened by this successful work. Mr. Kernot.

Mr. Fred Lavis, of New York, considered the Paper to be extremely interesting, as describing a novel method of construction that had been carried to a successful conclusion. The utility of this method and its adaptability to other cases of subaqueous tunnelling was very largely a matter of cost. It would naturally occur to engineers connected with work of a similar nature to make a comparison between the method described in the Paper and that of using a shield and compressed air. In considering the Author's statement that the lowest tender for construction by the shield and compressed-air method was about $2,000,000 higher than that for the design adopted, it must be remembered that the position of the tunnel, with reference to the bed of the Detroit River, was such that contractors had probably been led to the conclusion that the use of the shield method was practically prohibited by the terms of the specifications, except under very severe restrictions. It seemed reasonable to inquire whether, if a lower depth for the tunnel had been adopted, a much lower tender might not have been made for a shield-driven tunnel; and whether such lower tender might not have been sufficiently below the actual cost of the tunnel as built to have compensated for a higher cost of operation. Assuming that the summits were unchanged and that the gradient was increased from 1·5 to 1·75 per cent., the section under the river would have been lowered about 15 feet, which would give sufficient cover for fairly safe and economical construction by the shield method in the stiff clay found at this site. The increase in the gradient would not be a very serious consideration in this problem, in view of the fact that electricity was used as the motive power. The only important additional working-cost would be the actual power required to raise the weight of the trains passing through the tunnel through a height of 15 feet. Very little, if any, greater plant or engine-capacity would be required, and the only additional item of any importance would be fuel to produce the power. Various assumptions might be used to calculate the additional cost of this 15 feet of rise and fall, and for the traffic assumed by the Author —namely, twenty goods-trains and eighteen passenger-trains per Mr. Lavis.

Mr. Lavis. day, the additional cost of working would be between $2,000 and $5,000 (£400 and £1,000) per annum. These were wide limits, but assuming the maximum and assuming double the traffic, the justifiable expense to eliminate 15 feet of rise and fall would be $200,000 (£40,000), (interest at 5 per cent.). With electrical operation under the favourable conditions obtaining at Detroit, and for the amount of power consumed, it was believed that operating-expenses would be much lower than that, and it was to be hoped that the Author, who doubtless had access to correct data, could give some further information on this phase of the subject. Turning now to the question of the cost of the work, Mr. Lavis estimated that a shield-driven tunnel at the lower depth could have been built for, approximately, $225 (£45) per lineal foot. The cost of the water section of the East Boston tunnel—a double-track tunnel 25 feet high and 29 feet wide, outside dimensions —which had been driven through stiff blue clay under Boston Harbour, amounted to $240 (£48) per lineal foot. Mr. Copperthwaite[1] estimated the cost of a shield-driven tunnel, 21 feet 2½ inches inside diameter, in London clay, at about $175 (£35) per lineal foot unlined, the lining adding about $60 (£12) to this. With the steeper gradients proposed, the approach cuts would be shortened, but might be a little deeper at the portals. It would not be unfair to assume the cost of this portion to be unchanged and to take the length of the shield-driven tunnels at about 8,800 feet each, as against 8,310 feet actually built, at a cost of $4,544,912 for the tunnel section. The 8,800 feet of shield-driven tunnel at $225 per lineal foot would cost for the two tunnels $3,960,000, showing a saving of about $600,000 in construction to offset the increased operating-charges, capitalized, as shown, at a maximum of $200,000 for double the present traffic. The question of time had also to be considered: 12 months might be allowed from the time of letting the contract until the shields were ready to work, another 12 months for driving each of four shields 4,400 feet, 6 months for lining and 6 months for contingencies, all of which seemed to be ample, in view of the favourable conditions at Detroit as compared with the work done on the North River tunnels at New York. The total time then would be 3 years as against nearly 4 years actually required. He recognized, of course, that in this class of work there were many contingencies which could not be foreseen and might increase both the cost and

[1] "Tunnel Shields and the use of Compressed Air in Subaqueous Works," p. 368. London, 1906.

the time, but he believed sufficient had been said to show that there was hardly that immense difference of cost in favour of the method employed on the Detroit River tunnel, which the difference in the amount of the tenders might possibly lead one to think. Mr. Lavis.

Mr. GUSTAV LINDENTHAL considered that the method of building the tunnels described by the Author had the merit that it was happily adapted to the special local conditions. These were: first, the necessity of keeping the level of the subaqueous tunnel so that its roof would almost be level with the bottom of the river, which just had the necessary depth for navigation and no more; and secondly, the fact that the clay bottom of the river permitted the operation of dredging to be done with rather steep slopes and at comparatively little cost. If the bottom had been sand, mud, or other easily flowing material, that method would not have proved so efficient as the usual shield method with compressed air. This could readily be seen when the clay bottom of the Detroit River was compared with the mud bottom of the North River at New York, or with the mud, sand, and rock bottom of the East River. Dredging a trench in such material would have been very expensive, if not impossible, because of the soft bottom material flowing into the trench, or of the necessity of excavating submarine rock by one of the several methods in use—all of them, however, more expensive than the dredging in clay at the Detroit River. The successful and cheap completion of the tunnel under the Detroit River showed the correct judgment used in the selection of the method for the particular circumstances, for which too much credit could not be given to the Author. There was one detail in the completed tunnels on which more information would be welcome, namely, the construction of the tracks, consisting of wooden tie-blocks embedded and dowelled into the concrete with a drainage-gutter between the rails. Rapid corrosion of the rails due to the condensation of locomotive-gases, would, of course, be absent in this tunnel; and the formation of the track was such as also to permit of easy cleaning, a very important matter in sanitary respects. He would like to inquire, however, if the fastening of the tie-blocks in the concrete under the heavy tracks showed permanency; or whether any weakness had been observed which would indicate that the tie-blocks should occasionally, say every fourth or sixth, be in one piece, crossing the gutter. Experience on this question of tunnel-track was important in view of several other forms of construction now being experimented with, partly in the electrical subways of Philadelphia and New York, partly in the electrical Pennsylvania Railroad tunnels, and partly in tunnels used by steam-trains, wherein the Mr. Lindenthal.

Mr. Lindenthal. track was subject to rapid corrosion from condensed locomotive-gases. For the electrical equipment in the Detroit tunnel the use of a storage-battery was a very suitable arrangement for the regulation of the periodic fluctuations in the electrical current. It was not yet a usual feature in electrical installations for traction purposes, because of its large first cost, but nevertheless it was a wise economy.

Mr. Manton. Mr. A. Woodroffe Manton was specially interested in the costs of this bold method of carrying out the tunnel work, such figures being so seldom given in English papers. He did not think, however, that the Author had fully proved the methods adopted in both the approach and subaqueous tunnels to be more economical than the shield-and-clay-blanket method. This method which had been used in connection with the East and North River tunnels at New York, was first suggested by Mr. E. W. Moir, M. Inst. C.E., in 1891, when he obtained permission from the United States Government to dump clay over the Hudson tunnel as it approached the New York shore; and it was used by him again in connection with driving the Blackwall tunnel, by consent of the Thames Conservancy. To Mr. Manton the material at Detroit seemed to be almost ideal for the use of a shield, without the hazard and expense suggested by the Author; in fact, he would imagine that the method adopted ran the risk of possible failure, was much less speedy, and was at least quite as expensive, if not more so. With reference to the nearness of the tunnel extrados to the bed of the river, the East River tunnels at one point had a similar small cover, but a clay blanket (the clay for which had in that case to be brought about 60 miles) surmounted the difficulty very satisfactorily and economically; and, in fact, the East River tunnels were a much more hazardous undertaking. The two North River tunnels of the Pennsylvania Railroad in "Hudson silt" had evidently been constructed under very similar conditions to the Detroit River tunnels, and the shield system adopted had the great advantage that it was a very well proved one, and was not in any sense experimental: further, it could be carried on with speed and economy at all seasons of the year, being independent of currents, ice, and storms, which affected that river. Undoubtedly, the shield method would have been a much quicker one, and it must be remembered that each day was worth at least $1,000 to the railway company. This was the contractors' penalty, but probably it did not nearly represent the value to the company. The completion of these subaqueous tubes had been about 9 months behind the contract time, and taking the value of that period at only $1,000 per day, an extra cost of $275,000, Mr. Manton.

or more than $50 per lineal foot of single tube, was involved. The sinking and external concreting had occupied about 730 days—that was to say, the progress had been approximately 7 feet 4 inches of single tube per day of 24 hours, or about half the average progress made in the North River tunnels in the soft material. In the case of the approach tunnelling the average progress of the side shields per day per tube, after all the difficulties had been surmounted, was only 9 feet without compressed air, while the average progress in the North River tunnel with the standard shield was 14 feet under compressed air. With the adoption of shields no river-edge shafts need have been sunk. With reference to costs, Mr. Manton found it very difficult to understand how the "overhead charges," which were said to have been a uniform charge of 15 per cent. on labour and material, over the whole of the open cut, approach, and subaqueous work (of such different classes) could be as low as this. It would be interesting to know whether the inspectors' reports would be likely to include in this 15 per cent. the items of depreciation of equipment, timber, fuel, stores, repairs and renewals, workmen's compensation and other insurances, and office administration (both local and chief). The administration and workmen's compensation and other insurances would alone amount to nearly this percentage. In the case of the North River tunnels, the overhead charges, that was, the cost in addition to labour and material, must have amounted to between 30 and 35 per cent. Thus the cost, exclusive of contractors' profit, as worked out from the full information given in the Transactions of the American Society of Civil Engineers (1910), including the whole of the foregoing items, and costs for ordinary cast-iron lining and bolts, heavily-reinforced internal concrete lining (the reinforcement costing about $11 per lineal foot of single tube), grouting, ducts, steelwork, etc., averaged, in soft ground, about $345 (£69) per lineal foot of single tunnel. The cost of the rather larger Detroit River tunnel (and it did not seem quite clear why it should be larger than the Pennsylvania Railroad tunnels for third-rail operation) was $332 per lineal foot, allowing only 15 per cent. for overhead charges on labour and material alone. The latter cost, as given in the Paper (p. 29), was practically the same as that of the shield-driven St. Clair tunnel, of about the same cross section, constructed in probably similar material about 20 years ago, since which time very considerable advance had been made in experience of the construction and equipment of such tunnels, with corresponding reduction of cost. In conclusion, the shield method, with the precautionary clay blanket, would seem to Mr. Manton to have been a more certain method of carrying out this work, Mr. Manton. especially as regarded speed, and consequent final economy to the railroad-company, to whom the rapid completion of this tunnel and its approaches was undoubtedly a matter of the highest economical importance.

Mr. Meem. Mr. J. C. MEEM, of New York, felt that the Paper would be of great interest to engineers, and would make a valuable addition to the literature on the subject of tunnelling. His own interest in submerged tunnelling went back to the first published description of the construction of the submerged sewer-siphon under Shirley Gut in Boston, by Mr. Howard A. Carson, which work was alluded to on p. 10. Following this, he had made a study of submerged tunnels on a large scale, and in 1896 he read before the Brooklyn Engineers' Club[1] a Paper embodying the results of this study. In effect, the method proposed was to build a large wooden barrel with an inside diameter of 18 feet, to sink this in position on sills set by divers to approximate line and level in a dredged trench, to surround this barrel with concrete (deposited in loose bags) and afterwards to unwater the tube and build the tunnel inside. Except for the fact that a wood lining was used instead of a lining of metal, and other minor modifications, this project was in effect a rough forecast of a portion of the work described in the present Paper. Especial interest, however, attaching to the publication of this study in its relation to the present Paper, lay in the fact that, during the progress of the Detroit work described, Mr. Carson, in correspondence with Mr. Meem, had stated that a contractor, by virtue of having obtained a patent in connection with some submerged tunnel work which he had done, claimed a right to a royalty. Mr. Carson asked for some information concerning the matter from Mr. Meem, who sent him a copy of the Paper containing the study referred to, and although Mr. Meem did not know that it ever became necessary to use it, it showed how the publication of similar studies might be of value to the general engineering profession in such cases. In adopting the wooden barrel as the integral part of his scheme, Mr. Meem had been influenced by his connection with, and interest in, the construction of wooden-barrel sewer-outfalls under many of the piers of New York City. These barrels were usually 4 to 6 feet in diameter and circular in section, though some had been made oval. They were generally built of staves 4 inches thick, cut to radial lines and bound together by galvanized-iron bands, spaced at suitable intervals. They rested

[1] Brooklyn Engineers' Club, 1897 (Annual), "A Study of a Proposed Method of Building a Submerged Tunnel."

on sills bolted to the piles supporting the piers, and were held in place by capped timbers similarly affixed. Either short sections abutting were used, or preferably the lengths were made continuous, with the staves breaking joints at irregular intervals. The staves were creosoted for use in the New York waters, and this type of sewer gave very satisfactory results in every way, besides having a very low coefficient of friction. Mr. Meem had also used one of these wooden-barrel sewers to carry a temporary flow of storm-water, pending the breaking out of a large storm-sewer during the construction of a subway, the special advantages being that it was carried with absolute safety on timbering, while the material was available for use a second, or even a third time. He noticed the Author's allusion on p. 18 to the nature of some of the dredged material, and in connection with the usual assumption in regard to submerged structures, he would call especial attention to this remark, as showing that submerged structures bedded in clay or similar material could not possibly be under aqueous pressure over the whole area. Mr. Meem.

Professor C. L. DE MURALT, of the University of Michigan, was especially pleased with the part of the Paper which referred to the electrical equipment. It seemed to him that the specifications forming the basis for the tenders for this equipment had been drawn up in a particularly happy manner. They laid down in clear terms the general requirements with reference to electrical operation, and yet left to the various bidders the greatest possible freedom in the choice of details. Thus the various electric systems were placed on a strictly fair and at the same time on a directly comparable basis. He was slightly disappointed that the Author did not see his way clear to give the actual figures of the various tenders, but presumed there were good reasons against his doing so. After all, the percentage figures in the Table of comparison, taken together with the fact that the electrical equipment actually installed had cost in the neighbourhood of $1,000,000 (£200,000), gave a fair measure of the advantages of the three tenders, and of the three systems of electric traction which they represented. This comparison ended in a clear victory of the continuous-current system over the single-phase, the difference against the latter being 32 per cent. in first cost, and 20 per cent. in annual operating-costs (including fixed charges, operation, and maintenance). Considering the conditions under which this railway was worked, everybody, except single-phase enthusiasts, would have expected this to be the case. It was very interesting, however, to find the generally accepted view borne out so accurately in Prof. de Muralt.

Prof. de Muralt. a case of actual competitive bidding. The difference between the continuous-current system and the three-phase system was less prominent. The limited stretch thus far electrified did not bring out fully all the advantages of the latter. If the electric zone were extended to include, on either or both sides of the tunnel, sufficient additional track to make an electrical section, say, 100 miles in length, its advantages would be much more pronounced, and the comparison might end differently. The weight-characteristic of the three types of locomotives was also brought out very clearly by the three tenders. Three-phase locomotives were the lightest in weight, continuous-current locomotives came next, and single-phase locomotives were the heaviest of the three, the relation being as 1 : 1·23 : 1·48. This was a very important factor in heavy service. The extra weight carried in a single-phase locomotive, or to put it the other way, the smaller useful load which it would haul, was a very serious matter in the electrification of any railroad with dense traffic. There was not only the extra expense of carrying excess weight, but the capacity of the tracks was affected by limitation of the maximum useful load which could be passed over the line in a given time. A concrete example, which forcibly illustrated the importance of this locomotive weight-factor in any railway problem, had recently come to his notice in connection with the study of the advisability of introducing electric motive power on a western trunk-line where a fast through service had to be maintained over a section with severe gradients. The specified requirements of the electric locomotives were that they should be able to haul a trailing load of 400 tons at 50 miles per hour against a 1½-per cent. gradient (1 in 66). The steam-locomotives in use at present weighed approximately 150 tons including the tender, and even two of them were hardly adequate to maintain the specified speed on the gradient in question. It was found that the requirements could be satisfactorily met by a three-phase locomotive weighing about 68 tons or a continuous-current locomotive of about 95 tons. For the single-phase system the most practicable solution proved to be the adoption of locomotive-units of 105 tons each. Two of these, or a total locomotive-weight of 210 tons, were necessary to fulfil the service requirements on the 1½-per cent. gradient, although a single unit might be used on other sections of the line where the conditions were less severe. This meant in concrete terms that under steam operation 75 tons of locomotive had to be hauled for each 100 tons of revenue-bearing weight, with the single-phase system 52½ tons, with the continuous-current system 24 tons, and with the three-phase system 17 tons. All told, engineers must be very grateful to the Author for having brought out these points so clearly, and Professor de Muralt trusted that this very direct comparison would have the good effect of quieting some of the system-enthusiasts. When once the fiercely-asserted rival claims were silenced, they would all have a better opportunity to devote themselves to the real work of actually installing electricity as a motive power on main-line rails. Prof. de Muralt.

Mr. H. RAYNAR WILSON remarked that this tunnel was an international work, affecting both the United States and Canada. Having regard to the scare—set up by military men and politicians and not by engineers—as to a tunnel between England and France, it would be interesting to hear whether the respective Governments had been consulted as to the Detroit tunnel, and, if so, what reply had been given. With regard to the track, some information as to how lateral movement of the sleeper-blocks was guarded against would be useful. He presumed that no appreciable difference between the two types of rails used in the tunnel could yet be noticed. Mr. Wilson.

Dr. A. ZOLLINGER, of Berne, noticed that it seemed customary in America, in tunnelling under water, to employ single-track tunnels, grouped in various ways. It was true that in marly, clayey, or sandy soils, where timbering had to be resorted to, the single-track tunnel possessed the advantage of facilitating the excavation and work of lining, in consequence of the lower pressure encountered; but where a shield was used, or an advanced heading in reinforced concrete was driven, it became advisable to consider whether it would not be better to employ a double-track tunnel, rather than a twin single-track one. The cost would certainly be less for the double-track construction, which enabled the centres of the two lines of railway to be kept at the minimum distance apart, and would materially reduce the expense of the permanent way. From the maintenance point of view the double-track tunnel was less costly than two single-track tunnels. The natural ventilation in the case of a single-track tunnel was easier, as it was effected by the passage of the trains. The system adopted for crossing beneath the Detroit River was very ingenious, and enabled the number of the workmen to be greatly diminished, because nearly all the operations were conducted by mechanical power. Here a very important question arose: when the Mont Cenis tunnel was being constructed, as also in the case of the St. Gothard, it was still possible to find miners, timber-men, and skilled masons who had practised nothing else but those trades all their lives. At the present time it was very difficult to obtain expert workmen, and it became necessary to Dr. Zollinger.

Dr. Zollinger. make use of labourers. This rendered it obligatory to employ mechanical devices in the work to a much larger extent than formerly. In building the Lötschberg tunnel they had been compelled to execute almost all the excavation by machine-drilling because no miners were to be had. The same difficulty had been encountered in constructing the tunnel-lining because masons were not procurable. It would soon become necessary to make use of reinforced concrete, in order to obviate the employment of masonry with natural stone, which needed good artificers, otherwise the work was badly executed. The more recourse was had to the use of machinery, the more the man himself became a mere machine, and eventually the skilled craftsman would disappear. Comparing the cost of the under-water portion with that of the approach-tunnels, it appeared that in the former case the cost of the labour was only 20 per cent. of the total outlay, while in the latter case the cost of labour amounted to 50 to 53 per cent. of the total. The expenditure on a tunnel under water by the system adopted would be the same as for a tunnel through the ground, making use of the shield or of compressed air, but the system of submerging tubes rendered it practicable to keep the structure high and thus diminish the length of the inclined approaches. The tests of the concrete mixed in various proportions did not furnish very brilliant results. In his own practice greater strength was demanded; thus with Portland-cement mortar mixed in normal proportions (1 to 3 by weight), the compressive strength at 28 days should amount to a minimum of 3,129 lbs. per square inch. Concrete mixed in the proportion of $1 : 1\frac{1}{2} : 3$ should show in compression, after 28 days, 2,844 lbs. per square inch, and a mixture of $1 : 1 : 2$ would give a strength in compression of 3,556 lbs. per square inch. For the purposes of electric traction, continuous current on the third-rail system was employed which, though more costly in the equipment of the conductor, was preferable from the maintenance point of view in the case of a tunnel. The third rail did not interfere with the reconstruction work, as was found to be the case with overhead conductors, which, moreover, required a larger sectional area of tunnel in order to provide space for the trolley-bow involving extra cost in the construction of the work. Continuous current gave specially favourable results in the case of short runs with a heavy traffic. He did not know why it was contemplated in the Detroit tunnel to provide for few trains heavily laden. There was no necessity for this so far as goods-trains were concerned, because they could be formed up in the two adjoining stations. Express passenger-trains, whose composition had to remain unchanged, Dr. Zollinger. were the only ones which needed to pass through from side to side with a heavy load. There was always a desire evinced to carry out electric traction under the same conditions as steam traction; but this was a fallacy, because electric traction, if it was to be economical, must be conducted under suitable conditions; and that was the case only where numerous light trains running at a high speed were employed, and where the current was not called upon to propel certain trains five times as heavy as the average train. Heavy trains made too great a demand upon the power, and would not permit of the application of electric traction with more economical results than were obtained with steam traction.

The Author. The AUTHOR, in reply, expressed regret that umbrage had been taken at his reference to the possibility of the use of the Detroit method under conditions where hitherto the employment of the shield had been obligatory, and especially so in the case of Mr. Jacobs, whose success with the shield had been so marked. He had intended merely to point out the applicability of the trench method to problems in which the air-shield had certain disadvantages. The authority for the reasons given for ceasing work on the original tunnel-scheme in 1872 was Mr. Chesbrough.[1] In estimating what the tunnel might have cost by the air-shield method, Mr. Jacobs had no doubt taken into consideration the increase in prices for materials and labour since the St. Clair tunnel was built more than 20 years ago; but apparently he had not borne in mind that, even ignoring this possible cause for disparity, the St. Clair tunnel had cost $1·08 per cubic foot between portals, as compared with $0·89 within the same limits at Detroit. It was possible, too, that he had overlooked the necessity of a larger tunnel had the air-shield method been adopted. Experiments with the permanent type of track at Detroit had demonstrated the need for an underlying, shock-absorbing mass of concrete, which was present in the trench design but absent in the cast-iron-lined type of tunnel advocated by Mr. Jacobs. Hence, to provide the 18-foot headway above the rails, considered by the operating department of the railway as necessary for goods- and passenger-traffic, and also space for ballast under the sleepers as a cushion to obviate the chance of injury to the cast-iron lining, the internal diameter would have had to be increased from 20 feet to 21 feet, involving about 10 per cent. increase in the cubical contents, with a resulting increase in cost that would have far outweighed even Mr. Jacobs's assumed saving.

[1] Transactions of the American Society of Civil Engineers, vol. ii (1874), p. 235.

The Author. In reply to Mr. Jacobs's criticism that the Author's Table of comparative costs was in effect misleading, though not so intended, the information had been merely given for what it was worth, as a sidelight on the subject, and for the further purpose of stimulating discussion and drawing out just the kind of valuable data produced by Mr. Jacobs, of which too little appeared in technical proceedings for the advancement of the profession. It was interesting to note the difference in cost per cubic foot between the small-sized Hudson-Manhattan tunnels and the large-sized Pennsylvania Railroad North River tunnels which had been driven through material of the same character, and it was to be regretted that similar information had not been given for the Pennsylvania Railroad East River tunnel, the cost of which to the railroad company had been understood to largely exceed the North River costs. It was also to be regretted that the Author was not at liberty to disclose the contractors' profits on the various New York tunnels and at Detroit, as indicative of the margin that was considered proper to cover the risks of the two methods. The advantage in this respect had appeared to be in favour of the Detroit work. As to the Boston tunnel referred to by Mr. Lavis, it should be borne in mind that it was built through firm clay, practically free from water, without many of the onerous conditions that obtained at New York and at Detroit. However, discussion as to what might have been done at Detroit appeared to be academic in the face of what had actually occurred. After a peculiarly vigorous and open competition among the most experienced contractors in the country, several of whom had had wide experience with the air-pressures mentioned by Mr. Jacobs, and, moreover, had had the advantage not only of studying the situation on the ground but also, in at least one instance, of close personal knowledge of the subaqueous conditions at the time the first attempt was made to construct the tunnel in 1872, the trench design was selected at a price to the Company about $2,000,000 less than was actually bid on the air-shield design. The work had been successfully completed in accordance with the adopted design, without the interference to navigation about which Mr. Jacobs expressed concern, without accident, without injury to the health and life of employees, and with eminent satisfactory results to the Tunnel Company. It could, of course, now be said that with the air-shield method a blanket might have been used on the river-bed to prevent "blowing," and that thereby the cost might have been less; but the nine contractors who had tendered for the work had not so viewed the matter, evidently realizing that blankets

The Author.

imperfectly held air, obstructed waterways, and involved certain risks; that the cost of construction where these designs were then in use, as in the case of the East River Tunnel of the Pennsylvania Railroad, was liable to be excessive; and that the danger to the health and life of employees in the use of the air-shield at Detroit would have been accentuated by the presence of poisonous gases in the underlying material. As the work progressed the impression grew among those in responsible charge of the work, both engineers and contractors, that these fears were well grounded and that they had been well escaped by the adoption of the trench design. As stated by Mr. Jacobs, the accumulation of a great many years of experience with the air-shield design would, no doubt, in the future result in reduction of the cost of that type. For the same reason it might be expected that the building of future tunnels by the less aged Detroit method would show similarly happy results. Mr. Lavis had suggested that steeper gradients might have been used than 2 per cent. west-bound and 1½ per cent. east-bound, so as to provide a thicker roof over the tunnel. This had not been favoured by the Advisory Board because of the desire to minimize the strain on couplings and draw-bars, and the hazards and expenses always incidental to the frequent movement of long and heavy trains on steep gradients. Even with the adopted gradients the greatest care was required to prevent trains from breaking in two, especially when it was necessary to start a stalled train on an ascending gradient. As to the question of time, referred to by Mr. Boller and others, it was true that a year might have been saved in the tunnel-construction proper if the rate of progress had been attained that had been found possible with air-shield methods, but it was equally true that the same saving could have been effected at Detroit, had the Tunnel Company so desired, by requiring the contractor to employ more equipment and work from both ends. External conditions that developed after the commencment of the work, such as delays in acquiring property for the new Union Station, and in the elimination of neighbouring level crossings, rendered this requirement unnecessary. Even so the total time from beginning to completion of the work, 4 years, did not compare unfavourably with other tunnels, as for instance those constructed by the Pennsylvania Railroad under the East and North Rivers, each of which occupied approximately 5 years. The watertightness of the North and East River tunnels of the Pennsylvania Railroad was remarkable. In this connection the Table of comparative tunnel-leakages on the following page was given:—

The Author.

Order of Water-tightness.	Location.	River or Harbour.	Leakage, in Gallons, per 24 hours.	
			Per Sq. Ft. of Superficial Area.	Per Lineal Ft. Single Bore.
1	New York [1]	North River Pennsylvania Railroad	0·0005	0·15
2	Detroit	Detroit River	0·0027	0·85
3	Boston	Harbour	0·0034	1·35
4	New York [1]	East River Pennsylvania Railroad	0·0035 to 0·0070	1·00 to 2·00
5	Sarnia	St. Clair River	0·0080	2·46
6	New York	East River Battery	0·0102	1·68
7	New York	North River Hudson-Manhattan	0·0264	4·80 [2]

The 15 per cent. for overhead charges, about which Mr. Manton inquired, included administration and general expenses only, as the other items he mentioned were provided for in the labour and material costs. In response to the queries of Messrs. Lindenthal and Wilson as to the stability of the permanent track construction, short dowels in the concrete projected upwards into the tie-blocks so as to prevent lateral movement. No need had developed for bolting down the blocks, nor for occasionally extending ties in one piece across the gutters. Mr. Carson's and Mr. Meem's remarks were particularly interesting as bearing on the history of the art, especially as those of the latter had now first been called to the attention of the Author. Mr. Carson had well covered the reasons for finally favouring the adopted design, but for the information of Mr. Kernot it was explained that the requirement of continuity of strength from end to end of the subaqueous section had been considered best served by placing the reinforced lining without joints after the sections had been unwatered. As to electrification, interestingly touched upon by Professor de Muralt, Mr. Dawson, and Dr. Zollinger, extracts from the specifications would be too lengthy for inclusion in this Paper, but the Author

[1] Based on data furnished to the Author, 17th March, 1911.

[2] Mr. C. M. Jacobs has since explained that although this figure was correct when his Paper on "The Hudson River Tunnels of the Hudson and Manhattan Railroad Company" (Minutes of Proceedings Inst. C.E., vol. clxxxi, p. 169.) was written, the leakage now is at the rate of 2·28 gallons per 24 hours.—Sec. Inst. C.E., Sept. 1911.

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would repeat that the terms laid down therein had given the fullest opportunity for contractors to select and tender upon the system they preferred. The result had proved conclusively that for this particular problem the direct-current system was the cheapest in both operating and capital costs. That the system so selected was preferable from the standpoint of reliability had been shown in the data made public at the recent annual meeting of the American Institute of Electrical Engineers. Mr. E. B. Katte, of the New York Central Railroad, in comparing statistics for the direct-current electric zone of his company with those given for the alternating-current installation of the New York, New Haven and Hartford Railroad, gave the following figures:—

	New York Central.	New York, New Haven and Hartford.
Train-minute delays, due to electric troubles, last 6 months 1909	427	2,076
Locomotive-miles per locomotive-failure . . .	26,655	15,700

The Tunnel Company considered that, by the adoption of the direct-current system for this particular problem, there had been achieved the desired ends of economy, safety, and reliability, with the fullest opportunity for the future expansion of the electric zone, and with the avoidance of the large additional expenditure that would have been required for enlarging the tunnel had overhead conductors been adopted. The remarks on the fallacy of adapting "steam" methods to electric traction were applicable to lines worked entirely by electricity, but in the Detroit instance the electric zone was but a link in a chain of steam-traction, which rendered necessary the carrying through of trains unbroken.

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14 February, 1911.

ALEXANDER SIEMENS, President,
in the Chair.

The discussion upon Mr. W. J. Wilgus's Paper, "The Detroit River Tunnel, between Detroit, Michigan, and Windsor, Canada," was continued and concluded.