Morden entension of the City and South London Railway to cut down expenses, he cited their attempt to use in their foundry sand-throwing machines, which had been largely used in America. Several of those machines had been installed but, whilst each of them was capable of ramming moulds at quite four times the rate at which it could be done by manual labour, difficulties and obstacles had been raised against their use to such an extent as to render them ineffective, and they had been discarded. He would like to join with Mr. Jones in his praise of the work of the assistant engineers. On the northern section they had been fortunate in having less night work, but excellent work had been done by the assistant engineers of both the engineers' and the contractors' staffs. Mr. Curry.

Correspondence.

Mr. W. C. EASTON remarked that, from the short references (pp. 180, 185, and 189) to the enlargement of the tunnels under the river Thames at London Bridge, apparently little difficulty had been experienced there. The reference on p. 177 would appear to be the first record in the Proceedings of the 11-foot 6-inch tunnels driven in 1900. The late Mr. Greathead's Paper fully described the original 10-foot 2-inch tunnels under the river, now mentioned as being used only for storage of rolling stock. From Mr. Greathead's drawing,[1] the cover of the original tunnels under the bed of the river, mainly in London clay, was about 25 feet. What was the cover and the nature of the strata over the 11-foot 6-inch tunnels under the river-bed? The Authors referred (p. 189) to the fact that the clay in the roof at one point under the river Thames was very wet and unreliable, and they stated that as a consequence compressed-air working had been resorted to. The pressure used, 10 lbs. per square inch, indicated that the strata, although very wet, were strong enough to prevent the direct pressure of the river above from coming on the tunnel—a somewhat different condition from that experienced in one of Mr. Greathead's original 10-foot 2-inch tunnels[2] under the river. In view of Mr. Greathead's experience with one of the 10-foot 2-inch tunnels there, it was natural to expect that the greatest trouble would occur in the Mr. Easton.

[1] Minutes of Proceedings Inst. C.E., vol. cxxiii (1896), Plate 1, Fig. 4.
[2] *Ibid.*, p. 44.

Mr. Easton. under-river tunnels; and a little filling in of the gap between Mr. Greathead's Paper and the Authors' Paper would help to explain the apparent ease of the enlarging operations under the river.

Mr. Ferguson Mr. A. L. FERGUSON observed that the Authors did not mention the survey work carried out in connection with the enlargement. Needless to say, the whole of the old tunnels had had to be carefully surveyed throughout, in order to determine the best practicable realignment and regrading compatible with the limitations in deviation imposed by the shield and the necessity of reinstating the track at the end of each working-shift ready for next day's traffic—anything but an easy task. The system employed in surveying the numerous curves was that first used about 20 years ago by Mr. W. H. Shortt, M. Inst. C.E., in the realignment of some curves on a section of the London and South Western Railway—as it then was—and described by him in a Paper [1] read before The Institution in 1909. This method had been used with success throughout the work under discussion, and the engineers concerned had been very glad to have this comparatively little known, yet decidedly handy, method to resort to. He thought that the key-drawer, which had played such an important part in the work, might be described and illustrated in the Paper. The mishap at Stockwell in April, 1923, was not alluded to in the Paper, and a description of it would be interesting. In the much more serious slip that occurred in November, 1923, at Newington Causeway, a cavity large enough to accommodate a medium-sized house had been made in the roadway. He thought a section showing the effect of that accident would be worthy of inclusion in the Paper. That mishap inevitably raised the whole question whether it had really been worth while trying to carry out the enlargement and maintain the passenger-traffic at the same time. If the tunnels and all stations required for working-sites had been available throughout the 24 hours, much more rapid progress would have been possible, and the reconstructed line, with all its advantages, would have been reopened for public use the sooner in consequence. It would be interesting to know how much, if any, saving in cost had been effected by keeping the line open while reconstruction was going on. As an offset to the traffic receipts during this period, considerable expense had, of necessity, been incurred which would otherwise have been saved. For example, on the section of the line between Stockwell and Oval, where compressed-air working had been necessary, all the step-plate work at Portland Road crossover—a very

[1] Minutes of Proceedings Inst. C.E., vol. clxxvi (1909), p. 97.

slow and costly feature of the scheme—would have been avoided. Another section of the line where considerable saving would have been effected was that between Elephant and Castle and Borough stations. As mentioned in the Paper, that was the only length remaining of the old original 10-foot 2-inch diameter tunnels. There were some very sharp curves on that length in both tunnels and, as stated in the Paper, after these curves had been eased, as far as the small deviation permitted by the shield allowed, the iron had been taken out again, and rebuilt to a better alignment by hand. As, however, the track had to be maintained for the daily working of traffic, only a relatively small set-over could be effected. If the line had been closed, a still better alignment could have been obtained in one operation than had been actually possible in two, and at a substantial saving of cost and time. Was it not a fact that, when the original 10-foot 2-inch northbound tunnel was driven, nearly 40 years ago, an irruption of sand and gravel took place at the site of the later mishap at Newington Causeway, and the work had eventually to be completed, as in the present instance, under compressed air? It was easy, he knew, to be wise afterwards, but was it not almost too great a risk to have taken to attempt to disturb this bad ground again, working in free air, and with the tunnel in daily use for passenger-traffic, even allowing for the special precautions taken which were described in the Paper? Should any general enlargement of tube railways ever be contemplated, the experiences of the work described in the Paper should prove of the utmost value. Mr. Ferguson.

Mr. R. E. TICKELL remarked that a large part of the tunnel-enlargement work had been carried out by administration, which necessitated some system of cost-keeping, the principal object being to show the actual expenditure during progress, compared with the estimated cost per linear yard of the various sizes and descriptions of tunnels. There were forty different varieties in the size and construction of tunnels; work was usually proceeding simultaneously at fifty or sixty faces underground and at two or three depots above ground. Each description of work required separate accounts for labour, materials, transport, and overhead charges, so that the periodical measure bills eventually expanded to a list of sixty-four accounts, made up of 256 separate items. The time-keepers' books, pay-sheets, purchase-journals, and store-issue sheets were the finished products of the accounts department, but they were only the raw materials for any cost system, and had to be abstracted to the various cost accounts and correlated with the engineers' measurements of the work. The problem had been to devise some Mr. Tickell.

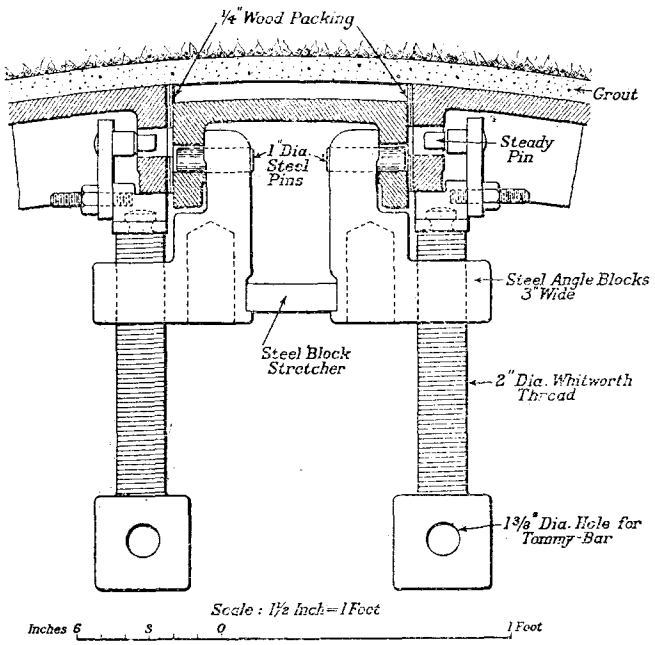
Mr. Tickell. system which should be so simple that it would run by itself without any clerical staff. That ideal had not been quite realized, but the nearest approach had been arrived at, with a staff consisting of one cost engineer and two clerks. The clerks occupied their spare time in assisting in the cashier's department. The cost books were of foolscap size, with sectional paper in quarter-inch squares, and these were ruled by hand for the various account forms and diagrams, which were kept plotted, showing the progress of the tunnels and the expenditure every week. Printed forms and large ledgers were avoided. One exception was, however, made, namely, a series of large-scale diagrams showing the progress of the tunnels in rings per week upon sheets of double-elephant size. Two sheets (northbound and southbound) were provided for each length between adjacent stations. The left-hand column gave the date of each week like a calendar, filled in for a little more than 2 years ahead, which was the estimated time for completion. Horizontal lines across the sheet were drawn for each week. The body of the sheet was closely ruled in vertical columns representing each ring in the length of the existing tunnel from station to station; the sizes of the intended enlargements were written at the head of the vertical columns. Upon these sheets it was easy to plot the position where work was started on any particular ring, at the actual date, and the weekly progress of so many rings in each direction appeared as a line sloping down the sheet from the peak where the start was made. Two or three of these peaks would appear on the sheet as fresh faces were opened, and the sloping lines of progress could at any time be projected forward with tolerable accuracy from each peak; at the intersection of two of these lines the date of completion for a particular length of tunnel could be read from the calendar. The labour costs were kept in loose-leaf ledger form, having a separate series of pages for each description of tunnel. The cost of each gang was entered weekly in a money column, together with the number of rings built by the gang during the week. The columns were totalled weekly and monthly, so that the total cost to date could be seen at any time. The results were shown in shillings per ring, and were converted to the cost per yard in a monthly summary. The principal materials were the cast-iron segments, bolts, etc., the quantities of which were known beforehand and easily accounted. Timber, lime, cement, consumable stores, and tools were more difficult to allocate. For the purpose of correct delivery a "train list" of all stores required at each tunnel-face had to be made out daily and posted up in the depot for the use of the loading-gangs. These lists were subsequently priced out

as store-issues, from which the approximate cost per ring could be obtained for each description of tunnel. These preliminary costs, however, required a number of corrections and additions. Timber, for instance, issued to one length of tunnel would be moved on and reused at other faces; fuel, lubricants, and a great variety of petty stores escaped entry in the "train lists." The value of these miscellaneous stores was, however, found to be generally distributed in proportion to the labour on each size of tunnel, with the exception of the shield-driven tunnels, where considerably less timber was used. At the commencement of the work a guess had to be made at the percentage in question, which was subsequently corrected by means of a diagram showing the monthly expenditure of miscellaneous stores as a percentage of the wages. The final allocation worked out at 10 per cent. upon the wages for shield-driven tunnels, and 12½ per cent. for hand-driven tunnels. The carting of surplus spoil was paid for by contracts per cubic yard, which presented no difficulty. The prime costs of underground labour, materials, and carting, were thus apportioned to the cost accounts within very small limits of error by actual records of time and measurements of quantity. To this prime cost a percentage had to be added for work at the depots, storage and handling of materials, workshops, depreciation of plant, and other overhead charges. Diagrams were plotted to obtain this percentage, and corrections were made as the works progressed. The final figure worked out at 28 per cent. of the prime cost of the measured works. The estimates were made just after the war, at a time of great uncertainty about future costs of labour and materials, and the Consulting Engineers were to be congratulated upon their foresight, for the actual costs worked out remarkably close to their original estimates, and showed a balance upon the right side of the ledger. A bonus scheme was introduced in February, 1923, at an early stage of the work, which materially influenced the costs. When the first shields were started a progress of only twelve rings per week was being made, which was much less than a preliminary experiment had proved to be feasible. The men were therefore offered a bonus of 2 hours' pay for every additional ring over twelve per week. The best gangs thereafter doubled their progress. The men received an increase of 42 per cent. on their wages, and simultaneously reduced the labour cost per ring by 29 per cent. Mr. Tickell

Mr. JONES, in reply to the Correspondence, remarked that the late Mr. Greathead's original 10-foot 2-inch tunnels crossed the Thames upstream of London Bridge, passing under the Old Swan Pier and along Swan Lane to the terminal station near the Mr. Jones.

Mr. Jones. Monument. Owing to the narrowness of Swan Lane, the up tunnel was driven immediately above the down tunnel and on a rising gradient of 1 in 40, piercing the gravel at 60 yards from the north side of the river, at 40 feet below Trinity high-water level, the shield entering the solid clay again 50 yards farther north. It was in this length of tunnel that compressed-air working was resorted to, not the length under the river as stated by Mr. Easton. The general stratum encountered was identical with that in the bed of the river, and the air-pressure required to keep back the

Fig. 20.

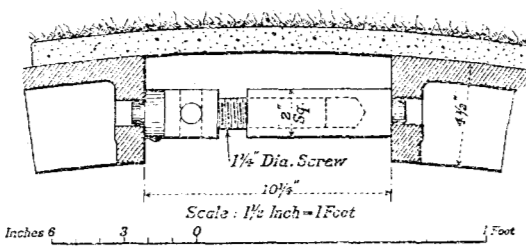


water was approximately equal to the hydrostatic head, varying with the height of the tide. The new 11-foot 6-inch tunnels crossed the river on the downstream side of London Bridge and ran approximately at the same level, the crown of the tunnels being 66 feet below Trinity high-water level at the south bank of the river and 63 feet below at the north bank, the cover at the deepest part of the river being about 35 feet, mostly of clay. Frequent borings put up 10 feet through the roof of the 11-foot 6-inch tunnels before enlargement showed solid clay, mainly dry; but at the point where it was decided to proceed in compressed air, the clay was found to

be wet enough to break away if not immediately supported. The saturated condition was probably due to a gravel-filled depression in the clay ; an air-pressure of 10 lbs. per square inch was sufficient to dry the ground and enable the work to proceed with ease and confidence. *Fig. 20* showed the key-drawer, which was designed by the Consulting Engineers and was self-explanatory ; it was made entirely of Armstrong-Whitworth " Vibrac " steel. The keys had usually been drawn quite easily, but where, owing to a " tight key " when building the ring, the wood packings had been omitted and the rough unplaned surfaces of the flanges came together, the removal of the key had been extremely difficult ; the apparatus would, however, either move the key or tear out a piece of the flange. After the removal of the key, the screw stretcher shown in *Fig. 21* had been inserted temporarily when it was not proposed to proceed at once with the removal of the ring.

Mr. Jones

Fig. 21.



The mishap at Stockwell in 1923 had been referred to by Mr. David Hay in the Discussion. The irruption of gravel in the tunnel amounted to about 230 cubic yards and entailed the closing of the line for 3 weeks. It had been possible in that case to remove the material from the tunnel and build the iron lining across the " break " without resorting to compressed air.

Mr. Ferguson had raised the question whether, in view of these mishaps, it had really been worth while to attempt to carry out the enlargement while keeping the railway open. The directors of the railway had carefully weighed the pros and cons of this matter before the mishaps referred to, which were obviously not factors in the equation ; material factors had been the necessity of preserving the goodwill and the obligation not to discharge any of the railway-company's employees in consequence of the carrying-out of the enlargement. Had the directors decided to close the railway to passenger traffic, the crossover tunnels at South Island Place and Portland Place (Fig. 3, Plate 3) would not have been required, but the

Mr. Jones. saving in time would not have been anything like that suggested by Mr. Ferguson.

All the stations which were practicable as working-sites had been so used. The important stations at the Bank and Elephant and Castle were quite impracticable, on account not only of the layout of the underground passages and the surface sites, which did not lend themselves to this purpose, but also of the insuperable difficulty of street traffic-congestion which would have been created at those points. All the working sites had been worked to their utmost capacity; the sidings had been completely filled in the daytime by the loaded wagons from the night working; the whole of the day shift had been required for the discharging and reloading of the wagons for the following night shift. Double-shift working from those sites had therefore been out of the question. The only way in which time could have been gained by closing the railway and instituting double-shift working would have been to sink numerous temporary working-shafts in the streets, as had been done in the short compressed-air section in Clapham Road (Fig. 3, Plate 3). That would, however, have been impossible in the City, and would have no doubt raised very strenuous objection in the Borough of Southwark. He was of opinion that the directors of the railway had been amply justified in their decision to keep the southern section of the railway open during reconstruction.

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12 April, 1927.

FREDERICK PALMER, C.I.E., President,
in the Chair.

The discussion on the Paper by Messrs. Jones and Curry "Enlargement of the City and South London Railway Tunnels," was continued and concluded.
