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DISCUSSION

The Jubilee Line

1. The project

E. W. CUTHBERT

2. Construction from Baker Street to Bond Street exclusive and from Admiralty Arch to Aldwych

A. C. LYONS

3. Construction from Bond Street station to Admiralty Arch

B. L. BUBBERS

Mr Cuthbert

The Paper gives the long history of the Jubilee Line since the London Plan Committee proposals of 1946. On 1 May, 1979, Stage I was opened to passenger traffic. It was opened with 1972 Mark II crew operated stock, but by 1984 this stock should be replaced with one man operated trains. In the meantime Neasden depot will be improved and equipped for centralized traffic control and the track layout between Stanmore and Finchley Road will be simplified. The signalling will be modernized and prepared for automatic train operation (ATO). It is not possible to forecast when Stages II and III will proceed.

150. Traffic is building up satisfactorily on the tunnel section of the line between Baker Street and Charing Cross, but its full potential will not be reached unless and until Stages II and III are constructed. Within a few days of opening, the peak hour passenger load has reached 8500 between Baker Street and Bond Street, out of the 10 000 forecast mentioned in the Paper. In the northbound direction the build-up has been slower, but the Bakerloo Line is carrying more than forecast.

151. The summary of costs in Appendix 1 indicates that the tunnel section of Stage I has cost about £13 million per route kilometre, including lands and electric power generation and distribution, but the 1979 figure would be £20-25 million per route kilometre.

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Mr E. R. Harding, Mott, Hay & Anderson

Almost the first decision of London Transport after the line was authorized in August 1971 was to fix the date for erection of the road deck at Bond Street for August Bank Holiday 1972, to be followed by the deck in the Charing Cross forecourt the following Easter. A preliminary contract was let to confirm that there were no services in the positions where the supporting piles were to go. We had previously obtained from the statutory authorities their supposed positions. This work was carried out at night and on Sundays only, with one lane closed at a time.

153. The most significant and unexpected find was a 30 in. water main which was encountered when we extended one hole to confirm the position of the Westminster City sewer. It was under a 24 in. water main which we knew about and had 100 ft head of water. The water board did not know that it was on that side of the road. It had been diverted locally within the width of the excavation and is now on its original alignment.

154. It was originally intended to bore the supporting piles at night but the GLC suggested rather at the last minute that these should be done over the Easter week-end and that Oxford Street could be closed for this period. This gave us about four weeks to get things organized.

155. Before the road deck could be erected the Westminster City sewer had to be diverted round the head of the escalator tunnel. The intersection chamber was at the bottom of the ramp in Stratford Place.

156. Balfour Beatty sublet the fabrication and erection of the road deck to Markhams who were ready to leave the site at 5 a.m. on the Monday morning, 7 h ahead of schedule. They actually left a couple of hours later after correcting some minor discrepancies. Balfour Beatty were then left with about 24 h for putting up the hoardings etc.

157. In November 1972 the traffic in Oxford Street was restricted to buses and taxis and a little later South Molton Street was made into a pedestrian precinct. If only we had known and been allowed to design a simpler structure!

Mr K. H. Moore, Edmund Nuttall Ltd

My company was responsible for the high level part of the new Charing Cross underground station which really meant rebuilding the old Strand station ticket hall plus some service tunnels and escalator work and pedestrian subways.

159. One of the working sites was on the umbrella over the ticket hall and like the other two sites was very limited in area. The umbrella was supported on pads and bored piles and as described in the Paper was erected and dismantled in a week-end. The concept of the umbrella is brilliant and a credit to those engineers concerned. Lifting selected panels at week-ends enabled us to fleet through the steelwork of the new roof and erect close up under the umbrella.

160. The tunnel miners involved on this contract were independent, skilled and productive men, but of late those in the London area have formed themselves into a group which appears to be similar in aim to the union locals in North America. It would be tragic if the corruption associated with that system were imported into the UK.

161. Mr Lyons refers in § 59 to the complexity of the work at Charing Cross. A normal remeasurement type of contract was used and this complexity caused an excessive amount of engineers' time to be used to process and administer

variations. It would seem more sensible in such reconstruction work to use cost-reimbursement plus competitive fees.

162. In § 44 a comment is made that all expanded linings produce difficulties in controlling the roll, but we have not had this trouble with Tatsej linings.

Mr R. A. Langfield, Charles Brand and Son Ltd

Referring to contract 540, Mr Lyons states (§ 45) that one of the shields squatted. It was reverse squat—a decrease in horizontal diameter. A large cutting edge bead was fitted and after driving for a shield length the shield returned to its correct shape. A horizontal strut was fitted across axis to prevent a recurrence.

164. The Mindev Impactor introduced on the contract was not a sophisticated machine (nor was it intended to be), but it was seen as a significant mechanical aid to excavation. Some (not all) of the breakdowns were associated with the mounting of the machine in the shields. We are not alone in learning the lesson that the mounting of such equipment should allow some flexibility or, alternatively, that the equipment should be mounted on a suitably modified front sledge behind a small shield.

165. Originally, contract 540 contained 2862 rings of cast iron in four lengths, and 2235 rings of expanded precast concrete lining in three lengths. In fact, only 1263 rings of cast iron were built, in eight lengths, and 3565 rings of concrete lining, in seven lengths. For the longer runs of cast iron a tail was fitted to the shield, but where short runs of cast iron were introduced because of unforeseen poor ground, these rings were built without the aid of a shield tail and not without some difficulty.

166. My first reaction on seeing the drawing of the concrete lining was that it contained too many segments. Having been brought up on six segments in 12 ft grey iron, and twelve in the Victoria Line expanded lining, the jump to 20 segments and two wedges seemed too great. I would have expected 16 segments and two wedges to have reduced the stresses adequately, and would be glad if the Authors would comment. We recently had a preview of the lining for Stage II but the only change has been to the longitudinal joint detail.

167. Mr Cuthbert points out that Baker Street is expected to operate at only two-thirds capacity under Stage I. It is surely a great pity that further stages cannot be constructed to a rolling programme rather than by a continuation of the earlier stop/start system.

Mr A. Neden, Balfour Beatty Construction Ltd

Table 4 shows the cost of tunnel bolts for a 5750 mm dia. tunnel (this being in the middle of the range of tunnel sizes driven at Bond Street). At Bond Street some 152 600 bolts ranging in size from M20 to M36 were measured in the final account. Assuming a 30% mark-up for contractors' overheads and profit, the cost to the client comes to more than £1·3 million.

169. It is stated in Mr Bubber's Paper that the 3850 mm dia. pilot for the lower escalator was driven uphill. This was the intention, but after only one or two rings it was thought easier and safer to continue uphill with a 2250 mm dia. pilot. The 3850 mm dia. pilot was then driven downhill.

170. The mid-level concourse and lower escalator were driven through London Clay in compressed air. The heat given off by the setting grout could

not be dissipated as there was little leakage of air. This resulted in unacceptably high temperatures and a high turnover of mining labour. The problem was overcome by the installation of a 5 t/h air-conditioner, the pipes for the cooling water being let into the low pressure air mains through the airlock.

171. There seem to be two schools of thought concerning panel sizes for the road decks: at Charing Cross the panels seemed to be rather large whereas at Bond Street they were smaller and could be handled quite easily by the site mobile crane.

172. The following points may be useful in a future design of a road deck.

173. The panels were steel trays filled with asphalt. In theory they were supported along two sides; in practice, due to distortion during fabrication, they bowed along their supporting edges with the result that when traffic came on to them there was a lot of noise. I would recommend a different method of support (e.g., corner supports).

174. Manholes should be provided in some of the panels to give access to cable draw pits etc., and to assist in the construction work. Open grilles could be easily substituted if more ventilation were required beneath the deck.

175. The clearance between the panels was quite generous and, with creep, rather large gaps occurred, which caused accidents to members of the public.

176. As the work proceeded, the steelwork supporting the panels also supported the services as they were exposed. Much use was made of Lindaptors bolted to the flanges; unfortunately, with the vibration from the traffic, they kept working loose. It would be preferable if a series of support points were welded to or drilled in the beams in the fabrication shop and a definite allowance were made in the design for the loads of the supported services.

177. The steelwork supporting the walkway panels was independent of the

Table 4. Tunnel bolts for a 5750 mm dia. tunnel

	Cost, £ (1979 prices)
100 No. M24 × 120 bolts—cost £43 per 100	43.00
Purchase additional 15% to cover losses at mining stage	6.45
Purchase additional 23% to cover losses at caulking stage	9.89
Cost of handling 138 bolts by yard gang at 1p each	1.38
Cost of handling bolts by mining gang (8 miner shifts to advance 1 ring of 5750 mm dia. tunnel; 25% of this effort is spent on building; 36% of building effort is spent handling bolts; assume miner gets £60 per shift; add 15% for labour 'on costs': $8 \times 0.25 \times 0.36 \times £60 \times 1.15 = £49.68$ for bolts of one ring of tunnel lining; i.e. for 84 bolts)	
Cost for 100 bolts	59.14
Cost of handling bolts by caulking gang (0.080 man hours per bolt; assume caulkers get £6/h; add 15% for labour 'on costs')	
Cost for 100 bolts	55.20
Total cost per 100 bolts	175.06

road deck steelwork and simply sat on the pavement. In theory nothing could be simpler; in practice it was rather difficult to get the two types of deck to marry up. It would be preferable to cantilever the walkway support out from the main road deck steelwork, which would also keep the original pavement free for access to the services.

178. The bottoms of the approach ramps were made up in asphalt. Unfortunately little thought seemed to have been given to rainwater flowing down the gutters on the uphill sides of the structure. Such ramps should, if at all possible, run back to a gully.

179. The design provided for timber fenders to be bolted to the road deck panels to protect the pedestrians from vehicles. The holding-down bolts were screwed either into nuts welded to the underside of the panels or, where this was not possible, into tapped blind holes. In practice it proved a time-consuming business getting the bolts into and out of their holes and perhaps a T headed bolt dropped into a slot and turned would prove easier to use.

180. Supports for hoarding around the perimeter of the deck should be provided. Neither hoardings nor fenders should oversail from one panel to the next, so as to allow individual panels to be lifted out without delay.

181. The steelwork under the deck should be painted white to improve the level of illumination. Cables for the under-deck lighting and the traffic signals and bollards should be routed to avoid steelwork that will be lifted during the life of the deck.

182. The preparatory work prior to the deck erection was hampered by the slow mobilization of the various statutory authorities. They claimed that although they were aware that the project was going to occur and discussions had taken place, the placing of orders on them, and hence the mobilizing of their contractors, happened rather late.

183. One of the results of this lateness was the undermining of the ground beams beneath the ramps so that an old cast iron gas main could be changed for a steel one. This meant that the main contractor and the gas board's contractor were working to a deadline—the deck erection—in close proximity to each other in a very busy street.

184. The electricity board should be asked to provide quick-blowing fuses in their link boxes around the site of the road deck before any construction work is started.

185. The water board's services seem well protected by stop valves, but the gas board's were not. A practical demonstration was given of the usefulness of stop valves on a gas main during the life of the deck—and that was with a small pipe!

186. While it seemed that everyone with any responsibility connected with Oxford Street was very concerned about the deck erection, it was rather the opposite in the period prior to deck removal, the attitude being, 'It's only the deck erection in reverse and that went alright.' Of course this was far from the case as once the deck was removed the rubbish had to be cleared, followed by the laying of the kerbs, road asphalt and paving as well as the installation of the street lights and traffic signal posts.

187. The requirements for the reinstated road *must* be frozen three months before deck removal; unfortunately, this was not the case at Bond Street. Only the longer Easter week-end of four days will suffice for a deck removal and reinstatement of the road.

Mr E. F. Humphries, G. Maunsell & Partners

Figure 16 shows the method by which the Eleanor Cross was carried on the relatively short stubby columns. I note with interest that they are sited right over the running tunnels. I would have thought that a method would have been devised whereby the loads were taken on each side of the running tunnels and bridged across to catch the loads coming down from above. I would have thought that the load on the roof of the tunnel might have caused distress to the tunnel in the long term, causing reduction in vertical and increase in horizontal dimensions of the cross-section of the tunnel. I would be grateful if Mr Lyons would give the reasons for the way it was done.

189. I am surprised at the settlement of about 90 mm (Fig. 18) at Grand Buildings, Trafalgar Square. To have risked such settlement in a brick building must have required a considerable degree of engineering courage, when perhaps all fears could have been put to rest by means of some underpinning and strengthening below.

Mr R. Watts, Balfour Beatty Construction Ltd

At Bond Street considerable difficulty was found in getting any information as to the loads the sewers were likely to carry, so difficulty was experienced in planning the work. However, this was taken up with the authorities and no accidents occurred causing flooding of the site.

191. The Bond Street contract was let on the use of only one 5750 mm dia. shaft. This proved rather difficult from a contracting point of view as material had to be got in and taken out of the same shaft. Would it have been possible to have used two smaller shafts or, possibly, one larger shaft which would have enabled two access arrangements to have been installed?

192. The main problem of driving the escalator shaft in compressed air was the humidity. Once this had been dealt with, the mining labour got to work in high temperatures.

193. The designs so far used in London undergrounds have been based on the use of hand labour, and this is becoming increasingly difficult. More standardization to enable machinery to be used more extensively would make life much easier. Have the Authors considered modifications of this nature for their designs for the future?

Mr B. Gonsalves, John Mowlem & Co. Ltd

In the Baker Street contract, the problems were associated mainly with the shield-driven running tunnel drive. The first of these was the normal problem where ground falls out of the crown of the tunnel because of sand lenses. This was solved in the time-honoured fashion of using trailing headboards. We used about six. That occurred over the first half of the drive, and there were only about 500 rings to do.

195. Another problem associated with the clay was swelling. The shield had been designed to cope with 6 mm swell of the clay as it came off the tail of the shield, with a set of beads provided to cover a further 5 mm of swell. Almost as soon as the drive was started, the first set of beads had to be fitted. After fairly satisfactory progress for about 120 rings, the ground came on even further, and the excessive pressures which had to be applied to the rounds to drive home the wedges necessitated stopping and putting on a second set of beads. That catered

for a further 6 mm of swell, and seemed to solve that problem for the rest of the drive. So for about 350–360 rings the ground was actually swelling on about 20 mm as it came off the back of the shield.

196. The biggest problem was associated with the last 240–250 rings, where the clay appeared to be fairly good in the face, but as it came off the back of the shield large lumps were pulled out of the ground. This seemed to be caused by the very low cohesion. As the tail of the shield pulled over the surface the skin friction between the face of the clay and the back of the shield produced a dragging force which pulled fingers out of the clay. This was quite serious because it occurred over the whole top half of the cut face. As there were only 240 rings to do and all the concrete segments had been bored, the decision was made to use trailing headboards. We had 20 trailing headboards, which left about a 200 mm gap in between the steel poling boards. The clay still continued to pull on through these gaps, and we had to stop and plug them as we built the segments. This allowed us to get the tunnel built, but it would not have been satisfactory if there were a substantial number of rings to build. It explains partly the disappointing progress of the mechanized shield.

197. The shield was originally designed to be used with hand work miners: there were only 500 rings, and it was not considered necessary or economic to put in a machine. However, at the time, hand work miners were at a premium, and as a Westphalia became available from another contract we put that in. That enabled us to get the work done with twelve mechanized miners, and to that extent it justified itself.

198. It appears that there is some problem with the clay in the region of Regent's Park. Similar problems were reported in the driving of the Thames–Lea water tunnel,¹⁵ where trailing headboards provided some of the answers but, in some cases, the tunnel had to be stopped and a complete tail skin applied and cast iron rings put in.

Mr M. P. O'Reilly, Transport and Road Research Laboratory

Mr Cuthbert and his colleagues are to be congratulated on adding a further section to the London Underground. The section under consideration will extend eastwards in the fullness of time as far as Thamesmead. It is, of course, essential if London is not to ossify and become moribund that it continually regenerates itself. For two centuries west London has been in the ascendant and the east has declined in importance. Revitalization of the latter is now on the cards and the provision of efficient transport infrastructure is a prerequisite to that end.

200. As engineers we often divert attention from the magnitude of our achievements by concentration on technicalities and it would be useful if Mr Cuthbert could put this scheme into the perspective of the daily role played by the Underground getting London's work-force to their jobs. I find it most difficult to imagine what London would be like without the Tube.

201. As to the technicalities I would like to refer to § 49 of the Paper by Mr Lyons and suggest that perhaps the difference in ground deformations around the bolted and grouted cast-iron linings and the expanded concrete rings is not always as marked as suggests. Fig. 26, from Barratt and Tyler,¹⁶ shows that ground movements over the centre-line of the northbound tunnel at Regent's Park reached 16–18 mm; the settlement profile at the surface over the southbound tunnel (Fig. 27) completes the data given in Fig. 12. The engineering decision to use concrete segments wherever possible was, of course, the correct one.

202. As part of the studies carried out by the Transport and Road Research Laboratory at Regent's Park, vertical and horizontal loads were measured by load cells at the axis and crown of a ring of expanded concrete lining and monitoring is continuing. The results to September 1979 are shown in Fig. 28. The vertical load recorded has after $6\frac{1}{2}$ years reached about 60% of the overburden, with the horizontal load at the crown being about 40% of overburden.

203. The data on comprehensive settlements of Grand Buildings (§§ 73-76 and Figs 17 and 18) is of considerable interest. Rough calculations would suggest that the area of underground openings under the northern side of the building, near levelling pegs 6-8, 10 and 11, were 170-200 m², and that the area of the settlement trough was approximately 5 m². This would put the ground loss at about $2\frac{1}{2}$ % of the excavated volume—an extremely creditable

Fig. 26. Settlement over northbound tunnel at Regent's Park

performance, given the complexity of the tunnelling. Would Mr Lyons indicate what the actual values were?

204. The comment on the damage to buildings (§ 76) is noteworthy. Were any measurements of strain made on Grand Buildings? If so, was any attempt made to compare them with the criteria proposed by Burland and Wroth?¹⁷

Fig. 27. Surface settlement trough—southbound tunnel at Regent's Park; axis of tunnel 34 m below ground level

Fig. 28. Load cell readings at Regent's Park

The Laboratory has recently used photogrammetry to monitor building movements over a pedestrian tunnel under York Way, King's Cross. Measurements on site are reduced and reference marks are not required on the building.

205. Further information on the ratio of lost ground to excavated volume would be welcome from Mr Bubbers.

Mr A. J. S. Blanchfield, Freeman Fox & Partners

It would be appreciated if Mr Cuthbert could give some additional information concerning tolerances for tunnel and track location. In § 27, the reference to Follenfant *et al.* indicates that the track tolerance for line and level is ± 1.5 mm (The Victoria Line, § 1.15), which is a high standard for a medium speed line. However, due to inability to keep within the ± 25 mm construction tolerance for the tunnel rings, 97% of the track alignment on the Jubilee Line (§ 28) had to be 'altered'.

207. The basic track tolerances on the Hong Kong Mass Transit Railway are ± 3 mm for cross level and ± 5 mm for the lateral and vertical alignment of the rails. Careful attention was paid to the rate of change within these tolerances and the maximum permissible was specified as 1 : 1000 over a 3000 mm length. In the event, the combination of track construction to these tolerances and the use of Dewag bogies has given a remarkably jerk- and vibration-free ride which, in addition, is very quiet, having been compared favourably with rubber-tired systems.

208. Perhaps Mr Cuthbert could say what track tolerances were specified, whether an alignment within these was achieved over the altered 97% length, and whether he considers that a small increase in tunnel diameter, giving a greater construction tolerance, would not have led to improved track alignment.

Mr Cuthbert

In reply to a comment that metropolitan underground lines abroad usually have two tracks in one tunnel rather than two single line tunnels, I would favour whichever provides the more economical solution. To save expense London Transport tube railways usually have an island platform layout which results in the tracks being widely separated at the platform, thus making two single tunnels the economic solution for some distance on both sides of stations. Clear of the station I would favour a two-track tunnel, if that provided the cheaper solution, as it would give advantages in equipping, ventilation and maintenance. However, two single tunnels involve less excavation and thinner linings and in London conditions are usually cheaper.

210. Mr Langfield refers to the stop/start way in which London Transport undertakes its tunnelling work. This is true, but it is not the fault of London Transport. If funds could be made available we would gladly complete the Jubilee Line.

211. With reference to Mr Humphries' comments, in the construction of the Victoria Line the deep basement of Peter Robinson's was underpinned by a prestressed concrete slab immediately above the site of the southbound platform tunnel before tunnelling began, and no measurable settlement occurred during and after completion of the work. The case at Grand Buildings is very different. Here the considerable depth of ground between the foundations and the tunnels would have made underpinning uneconomic.

212. I can confirm **Mr Gonsalves'** remark about the ground encountered on the Thames-Lee tunnel main in the Regent's Park area, but the tunnel is $\frac{3}{4}$ mile to the north of the Jubilee Line.

213. **Mr O'Reilly** asks about the role of the Jubilee Line in relation to London Transport's task of getting people to work. Stage I accounts for 6% of the route mileage of the underground system and 6% of the total miles operated. Stages II and III together would add a further 5% to both items.

214. In reply to **Mr Blanchfield**, the deviations from the specified ± 25 mm construction tolerance for the tunnel rings were frequent and in some places considerable. Had a larger tolerance been specified and the tunnel diameter correspondingly increased, the relaxation could well have reduced the number of rings built out of tolerance, but the tunnels would probably have cost more. The track alignment actually obtained should give as good a ride as if the track had been installed to the original setting out.

215. Adjustments to line were more frequently necessary than to level and changes in cross level were not required. On straight track the standard achieved at the time of concreting corresponded to a maximum variation in offset of 4 mm between monuments 7000 mm apart.

216. After concreting, the track was marked for quality on the same basis as tracks generally on London Transport. The overall standard was found to be good, corresponding on straight track to a maximum variation between successive monuments of 6 mm.

Mr Lyons

I agree with **Mr Moore** that the problem of roll does not occur with all expanded linings, particularly those with a single wedging point. However, in order to increase the amount of expansion in the ring, so as to allow for swelling clay as mentioned by **Mr Gonsalves**, we put in two wedges instead of one. The wedges were either side at the knees, and until a mining gang was experienced it was difficult to get them to wedge up more or less the same amount to prevent roll occurring.

218. With respect to **Mr Langfield's** comments concerning the number of segments in the concrete running tunnel ring, this is influenced by the equipment to be supported. London Transport require a certain number of bolt holes to be provided in the ring at specified spacings, in order to hang their equipment. On the Victoria Line we had five bolt holes to a segment and a lot of segment breakages. For the Jubilee Line we switched to three bolt holes to a segment, reducing the length of the segment by 40%, but we had very few breakages. There is, however, no doubt that from a structural point of view a ring with 16 segments and two wedges would have been suitable.

219. **Mr Moore** questions the use of an admeasurement contract for the Charing Cross station (upper) works, and asks why cost reimbursement plus competitive fee was not used. This was because we could foresee no advantage to the client in this type of contract. Sufficient time was provided to prepare admeasurement contract documents, and contractors were willing to respond to the risks involved in pricing such documents.

220. It is difficult to imagine what further standardization **Mr Watts** has in mind, as standard linings throughout the size range are available for London Transport's ancillary tunnels. The running tunnels are also standardized to

interchangeable concrete and cast iron. The very nature of the ancillary tunnels, however, is labour-orientated, and it is difficult to imagine how this could be otherwise. This does not preclude the use of machinery in certain instances, as proved by Mowlem's at Baker Street station when constructing step-plate 1.

221. **Mr Gonsalves** points out the advantages of using trailing headboards when the clay does not stand up in the crown, and refers back to the Thames-Lea water tunnel. However, the rings built in that tunnel were bolted reinforced concrete, not cast iron.

222. On the question of settlement around expanded linings and bolted linings raised by **Mr O'Reilly**, Figs 11 and 12 show that there was less ground movement for the expanded lining than the bolted lining at similar depth. Fig. 26 was not included with the Paper as the northbound tunnel at Regent's Park is some 10 m shallower than the two tunnels directly compared. The settlement certainly was no worse than with the bolted lining, and I was rather put out by the fact that when we started the Baker Street to Bond Street contract we had to build some 1000 rings of expensive bolted lining, quite unnecessarily in my view, because the theory then, in certain quarters, was that there was more settlement with an expanded lining than with a bolted one. We certainly demonstrated that this was not the case.

223. The figures quoted by **Mr O'Reilly** for the hoop loads measured in the lining are of interest as they supplement information on measurements over one year in an expanded lining.¹⁸

224. The reason that we built the two 1800 mm dia. shafts at Charing Cross Strand over the tunnels, as queried by **Mr Humphries**, was that the calculations we prepared showed us that these interchange passages would not suffer, and it was much cheaper to do it that way. These shafts were incorporated into the upper machine chamber wall which also was above the interchange passages. The scheme suggested by **Mr Humphries** would have cost far more.

225. The cheapest solution was also adopted for Grand Buildings where, in spite of the very high volume of ground removed from beneath the building, no serious damage took place and the building remained in use throughout the execution of the works. Due to the large number of tunnels and cross passages the use of tunnel shields and of linings stressed against the ground to provide immediate support to the excavation was not realistic. Underpinning was considered but also disregarded because of the number of tunnels, its doubtful value over the actual method of construction and the phenomenal cost involved. **Mr O'Reilly's** figures are more-or-less correct, with our values coming out at a settlement trough area of 4.9 m² and an area of underground openings of 179 m², giving a ground loss of 2.74% of excavated volume. No measurements of strain were taken on the building although a number of glass 'tell-tales' were installed.

Mr Bubbers

Mr Neden makes some useful comments about the road deck. Certainly we appreciated that there were possible detailed shortcomings in the deck which can be taken into account in the future.

227. With reference to **Mr Watts'** contribution, sewer diversions at Bond Street were quite complex. Sewers subject to surcharge were indicated in the documents which laid down construction procedures in the vicinity and the

strengthening required. The ubiquitous Kings Scholar Pond sewer turned up yet again to bedevil the work, and this time the diversion involved was such that the crown of the new tunnel cut in and ran along the invert of the existing sewer, which made life rather complicated because it remained live during diversion. Nevertheless, that was overcome with some temporary strengthening and lining which contained the flowing effluent whilst the invert of the old sewer was removed and the new one constructed beneath ring by ring.

228. Mr Watts mentions the 5750 mm dia. shaft at Bond Street. I think our usual practice is to define the diameter and position of the shafts where they form part of the permanent works. On sites where no permanent shaft is required we like to leave the layout of the shafts to the contractor to suit his own purposes and equipment, but where shafts are defined by the permanent requirement, there may be a need to keep to the diameter specified. In the case at Bond Street it was a permanent draught relief shaft. I suppose it was open to the contractor—as, in fact, has happened on other contracts—to propose a different diameter. In this case it would have probably had to have been a larger diameter shaft rather than two.

229. Mr Watts also mentions the need for standardization and difficulties where hand excavation is involved. As designers we are acutely aware of the problems associated with tunnel construction by such methods. I believe we have long taken this into account as far as possible by providing drive lengths and sites which make the investment in mechanized excavating equipment worthwhile. Contractors have responded to this. Tunnel lining diameters and details too have been rationalized during lining metrication. Nevertheless much of the construction work has involved alteration to existing underground structures, often in difficult circumstances, whilst maintaining passenger flow; it is difficult to conceive that there can ever be much mechanization in such diverse situations.

230. With regard to Mr O'Reilly's contribution, I have certainly found that there has been an enormous amount of information in papers produced in the past, and it is of great use. I certainly hope that this Paper, with the discussion, provides data of use in the future. As Mr Langfield says, however, the industry needs more work so that we can all keep up the good work.

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