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Hong Kong Mass Transit Railway Modified Initial System

J. T. EDWARDS, C. R. COULSON, R. A. CHANING PEARCE, D. F. McINTOSH, A. J. R. WALKER, D. J. EASTWOOD, M. IMAMURA, H. DOHERTY, C. K. HASWELL, A. R. UMNEY, P. HALL, F. J. HANSEN, F. G. STOREY, G. O. ARCHER, R. A. LANGFIELD, R. L. TAYLOR, M. J. TAYLOR, W. J. GREIG & R. F. COUPERTHWAITE

The Authors

The Mass Transit Railway Corporation retained full control of construction and set up a strong management team for this purpose. This control was exercised through three groups:

(*a*) The Deputy Director (Engineering) managed the design process in liaison with the consulting engineers and was also responsible for inspection and acceptance of completed works.

(*b*) The Deputy Director (Construction) was responsible for the management of all contracts to the point of acceptance of completed works, responsibility for geographical sections of the work being delegated to construction managers. An important part of construction responsibility was the co-ordination of all interfaces between contracts, both civil and E&M, within the overall project framework.

(*c*) The Commercial Manager monitored all cost and programme changes and ensured that the Corporation's contractual interest and obligations were properly defined, recorded and maintained.

2. Radical delegation is a necessity in a project of this size and nature. The powers of the Engineer were vested in the Deputy Director (Engineering). All clauses of the conditions of contract relating to design and construction were delegated to the constultants. All other powers other than those relating to issue of certificates of completion, maintenance certificates, certification of final accounts and settlement of disputes, were delegated to the Deputy Director (Construction) and his Construction Manager.

3. Steps were taken to co-ordinate the planning and execution of the work with all bodies concerned, and minimize the disruption to the daily life of the population. The Public Works Department established a Mass Transit Adviser's Office as the focal point for contact between the Corporation and various arms of

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government. Mass Transit cells were established in the different departments of PWD dealing with highways, water supply, drainage, port works, building ordinances and land use. Similar cells were formed by the police, the fire services, the Home Affairs Department, and the private utility companies responsible for gas, electricity, telecommunications and transport services. A hierarchy of standing committees and liaison groups was set up with representation at appropriate levels of all concerned bodies to consider and resolve all problems. Problems which could not be resolved at a particular level were quickly elevated to higher levels to ensure speedy resolution. Notwithstanding the need for extensive consultation on many matters, considerable emphasis was placed on timely decision-taking, and *ad hoc* meetings were convened as necessary to ensure that outstanding problems were not permitted to affect construction. As much work as possible was done on utility diversion prior to commencement of construction, but in many instances sequential re-organization of services was crucial to the maintenance of contract programmes. Contact with the public was maintained through the Corporation's Public Relations Manager, and the City District Officer or the Government Home Affairs Department.

4. Progress was continuously monitored by regular weekly and monthly meetings at appropriate levels between contractors and Corporation staff. This ensured that appropriate action was taken to overcome incipient delays as soon as they became apparent. A hierarchical system of internal reporting was established to ensure that the Corporation was kept aware at regular monthly meetings of all time or cost overruns on all contracts and of the actions being taken to deal with them. Significant events affecting progress or relations with the public or government bodies were reported at daily executive meetings.

5. As is inevitable on projects of this size, changes were necessary. These emanated from design developments, interfaces with the E&M work, alterations in operational requirements or unforeseen conditions. A strict procedure was instituted to control all changes. This required the proposer to submit through his line manager an outline of the proposed change, with estimates of its probable cost and time effects. Following rapid circulation among all who were likely to be concerned, the proposal was considered at one of the twice-weekly divisional review meetings, chaired by the Engineering and Project Director, prior to submission to the Executive. This procedure allowed the principle underlying the change to be considered at the highest level prior to the expenditure of time and money on its development.

6. The Corporation regarded contractors' problems as its problems and actively encouraged its supervisory staff to work with contractors to devise solutions to overcome obstacles to progress. It also acknowledged that the implementation of these solutions could give rise to additional costs and was prepared to negotiate with contractors on an equitable sharing of these. The basis of these negotiations was generally reimbursement of costs clearly identified as a Corporation liability allied to attainment-related incentive payments.

7. Future service connections in the Mong Kok area in the Modified Initial System will enable a true service to operate between the Kwun Tong and the Tsuen Wan lines and on completion of the Tsuen Wan Line this area will become the most important interchange point between lines on the system.

8. Projected passenger traffic is substantially greater than on most, if not all, other systems. This, together with the limitations imposed on the design of stations by widths of roads and the density of building development, led to the adoption of

a basic station design similar to that in Tokyo. However, the long narrow concourse is less than ideal for the planning of passenger movements. The final layout of escalators and ticket gates for each station was arrived at only after careful study of the flow of passengers along platforms and the build-up of crowds around the exits and entrances at escalators.

9. Another factor which greatly influences the design of stations is the accommodation of the E&M plant, all of which has to be housed within the station structure; of this plant, that required for the environmental control system had the most effect on the design. To accommodate this plant would be a complex enough operation at any time. The situation was made more difficult by the fact that the selection of equipment and the preparation of detailed plant layouts was the responsibility of several E&M contractors, and the E&M contracts were not awarded until after the award of the civil contracts. The contract for the environmental control system, which was that which affected the station design most, was not awarded until more than a year after construction had started on the earlier stations. The civil contracts allowed for changes to be made in the required works to accommodate the detailed designs of the E&M facilities. The basic strategy adopted to co-ordinate the designs of the various E&M contractors and the civil works was for the consultants to prepare outline E&M layouts based on information provided by the E&M contractors. These layouts were used to define the civil works, and they constituted a restraint on the detailed design of the E&M contractors. In general, this procedure worked well though on occasions further later changes had to be made to the civil works.

10. In order to arrive at the final design for the Nathan Road interchange complex which includes Waterloo as well as Argyle and Prince Edward stations, outline designs were drawn up for no less than 21 schemes, each of which was studied in detail with regard to station and train loading, operational feasibility and principles, and junction layout and design.

11. The construction of the underground stations was let on a design-and-construct basis. The contracts required that the designs were submitted for the approval of the Engineer. The consultants were given the onerous task of processing the drawing and calculation submissions through to final approval. This required the handling, on nine station contracts and six tunnel contracts, of over 6000 drawings, excluding architectural details, together with associated calculations. Before approval could be given, comment from the Corporation as client and the Building Ordinance Office and Mass Transit Adviser's Office of the Public Works Department of the Hong Kong Government had to be reviewed and conflicting requirements resolved or reconciled.

12. Lok Fu station was constructed by Metro Joint Venture (MJV), an international consortium comprising Dragages of France, Hochtief of Germany, Gammon of Hong Kong and Sentab of Sweden. This station is partly in bored tunnel and partly in retained cut. The site was open and dewatering and temporary anchors led to a very neat form of wall construction commonly known as the Berlin-type wall.

13. At Kowloon Tong station two forms of construction were used. The central and straightforward section was built with conventional diaphragm walls while the Tokyo wall system, very similar to the Berlin-type wall, was used for the more complicated ends of the station. This system involved anchored king piles and lagging; in the event, the diaphragm wall construction took longer than was anticipated and the extent of the Tokyo wall was increased. Junctions between the

two systems required careful analysis to ensure structural compatibility, the Tokyo wall being set back from the permanent diaphragm wall to allow the extension within the Tokyo wall to line up with it.

14. Admiralty station is trapezoidal in plan in order to accommodate the tracks of the future Island Line, and also on account of the diversity of methods used to retain the ground. Both Admiralty and Chater are three-level stations, the bottom level at Chater being required for the storage of trains overnight. The two stations were built by MJV who retained Ove Arup as consultants for the work.

15. In geological terms the area in and around Hong Kong is formed of marine and deltaic deposits of the upper Palaeozoic era and lower Jurassic period and acid volcanic rocks of the upper Jurassic. These were intruded by a large acid granite batholith during the Cretaceous period.

16. Although in general Hong Kong has at its surface the volcanic rhyolite, most of the tunnels for the complete metro system will be through granite, ranging from the fresh to the completely weathered state. Some 47% of the 57 tunnel drives for the Modified Initial System were in soft ground driven with the aid of compressed air. When the construction of the metro system was first being considered there was very little experience of driving soft ground tunnels in Hong Kong although the art of rock tunnelling was well established. As a result trial tunnels and shafts were constructed which proved to be of great value in providing parameters for the design of the permanent tunnel works and for determining viable and economic methods of construction. Due to a variety of programme and construction restraints, separate tunnel access had to be provided between the cut-and-cover stations, resulting in average drive lengths of 300 m from a total of 15 access points for the seven tunnel contracts. Construction of the temporary works for each contract took up to 60% of the available construction time, the contractor's country of origin often influencing his selection of construction method as well as the type of tunnel lining employed.

17. The immersed tube lies throughout on a 2800 m radius curve. This enabled standard curvature to be used on the approaches, and as all units except the two end ones were identical, the same formwork could be used throughout.

18. Concerning the depot, timely completion was fundamental to the whole project. It contains the nerve centre of the railway—the control room, which regulates all automatic train movements and monitors the functioning of all services and stations down the line. In addition, all planning was based on track-laying and rail-related E&M installations proceeding in a linear manner from the depot to Choi Hung and on to Chater. The late decision to embark on the design and construction of a major commercial and residential complex above the depot posed considerable problems to both designers and constructors, and called for much ingenuity to ensure that the basic requirements of the railway were provided on time. Early completion of the line from Choi Hung station to Kowloon Bay station was also vital to the project as it formed a test track for commissioning of all the rolling stock which is assembled at the depot.

19. Kwun Tong station is noteworthy on account of its complexity. The only way in which the PWD requirements for grade separation could be met was to design an underpass on the longitudinal axis of the station. This involved restraints on the column positions, which were further restrained by the need to position a crossover near enough to the station to enable a 2 min headway to be achieved.

20. The development above the depot consisted of 41 blocks of residential

flats, the tallest being 26 storeys. Schools, shopping centres and full recreational facilities such as swimming pools were also provided. Regarding the 4 h fire barrier, two major requirements had to be met to protect the structure: these were reduction of heat flow to the upper surface, and control of movement so that fire injury stress would be limited. The depot analysis was in general carried out on a Univac 1106 computer using a program Planfram, adopting a system of linked plane frames. In order to assess the fire effects, an *ad hoc* program was developed to estimate heat flow, average temperature and temperature gradient through variously insulated beam-and-slab combinations subjected to the predicted fire load. The results were interpreted as free strains and used in conventional structural analysis to predict movements and member forces. Where necessary, structural protection has been achieved through increased concrete thickness, increased mesh covers to columns and beams and the application of vermiculite spray insulation. Additional reinforcement has been added where additional shears and moments could not be accommodated at reasonable load factors.

21. The setting up of a workshop for thermite welding in the depot, rather than carrying out the work in situ, ensured the highest possible rate of track-laying requiring occupation of the track bed, and also ensured the best possible and consistent conditions for making the welds—conditions such as are not often found in tunnels shortly after construction has been completed.

Mr G. A. Lance, Sir William Halcrow & Partners

I should like to comment on the design of the elliptical and flat-bottomed tunnel linings used on contract 107 (North Nathan Road tunnels). We at Sir William Halcrow & Partners were pleased when Brands approached us to assist them with the design of the crossover tunnels as we had previously been involved with the report for the Greater London Council in which elliptical-shaped road tunnels were proposed for use in the London Clay. Brands were initially considering the use of flat-bottomed rings in order to reduce the compressed air requirement. We proposed elliptical rings as a means of further reducing these requirements. From the site investigation data provided to tenderers, and from work carried out locally by Lumb,[1] we deduced soil modulus values which indicated that the completely decomposed granite generally varied over the site within the range 20–30 MN/m^2. At the northernmost crossover location, however, the soil data, although appearing contradictory, indicated a low strength soil of approximately 7–12 MN/m^2. We needed to confirm these values, bearing in mind that McKinlay[2] had suggested that in situ ground modulus values are generally higher than laboratory measured values. We therefore suggested to Brands that they carry out pressure-meter tests at the crossover locations. Values obtained from these tests in the event agreed closely with the values previously deduced from Lumb. We analysed the lining by firstly establishing the hoop load that would be generated by a circular lining having a diameter equal to the major axis of the ellipse. This load was then assumed to act within a circular lining of radius equal to the smaller radius of the ellipse, and a deflexion analysis was carried out to the Muir Wood[3] method. This method was then checked by use of a structural analysis computer program, Leap 4, and modelling of the ground stiffness through springs. Similar results were obtained from both methods. Our analysis of the elliptical rings showed that in only two crossover locations was there sufficient ground support to limit the deflexions across the horizontal axis to acceptable limits. A conventional flat-bottomed type ring was therefore designed for the northernmost location.

23. I should like to ask the Authors whether they had to take any special measures during erection to maintain the shape of these linings (such as tying across the axis), how quickly they were able to build the linings and whether this was quicker or slower than for conventional large rings, and if they measured the ground settlements above.

Mr M. J. Harris, Lansdowne International Ltd

Hand-dug caissons are an established method of construction in Hong Kong. There are many arguments for them, and certain sites in which there appear few economic arguments against them; furthermore, it is a way in which a lot of people there make their living. With one person down the hole digging and a person at the top winding the muck up, it is a basically unsafe method and it causes a lot of accidents. It brings an engineer, working in that sort of environment, to ask himself to what extent he is responsible, as an engineer of this Institution, for ensuring that the safety standards which would be required in his home country are carried out for work for which he is responsible—either as a designer or as a person working within the construction industry there. Perhaps it brings one to the question of whether or not we engineers working in design and construction in the UK rely for our safety standards on those engineers working on legislation and within the controlling bodies, rather than on our own professional standards.

Mr W. H. Law, Ove Arup & Partners

In Hong Kong, especially on the island site, we discovered a very high water table level, at about the road level, which is about +4 m PD. A major problem for building such a deep station as Pedder, for example, which is at three levels, extending down to about −35 m PD, is that we had (contrary to settlement) a flotation problem. The hand-dug caissons were dug down to rock level and sunk into the rock like the normal bored piles in clay with underream. Thus they act like tension piles, and the tension is taken up by putting adequate steel in the caisson itself. The amount of steel inside each caisson was adjusted to its proposed design load. In Pedder station the loads reach about 25 MN.

26. For the second stage for Tsuen Wan extension in contract 304, Ove Arup was a consultant to the contractor Dragages et Travaux Publics for an alternative design on a viaduct. We were involved from the pre-tender stage, submitting an alternative design, we helped in the negotiation with MTRC after gaining the contract and we finished the detailed design. I believe that the MTRC's open attitude towards the alternative design is tremendous, compared with the general attitude in the UK.

Mr P. H. Dawkins, The Henderson Busby Partnership

Where unacceptable settlement of buildings took place, what remedial action was taken and were the buildings reoccupied?

Mr G. G. Kibblewhite, Retired Kennedy & Donkin consultant

The interface which affects all disciplines is the rail. It is used to take the current back to the substations, and for signalling and all other communication, as well as being used to carry the trains.

29. The method adopted by the contractors to put in the Pandrol supports brought the Pandrol fixing very close to all the reinforcement in the track, and in

wet conditions the difficulty of maintaining insulation between rails and to earth becomes difficult. The resistance between rails varies greatly; when it is dry it can be 300Ω; but when it is wet (especially when it has been laid wet) it can be only 2Ω. I think that this is a weakness which has to be taken care of in the future far more than we did in Hong Kong, and I would like the Authors to comment.

The Chairman, Mr T. L. G. Deuce

It is said in Paper 8389 (§ 6) that it was a Government requirement to meet the whole of the capital and operating costs out of fare revenue, and to attract passengers by making the system convenient to use and making it attractive. I would be interested to know if there are any indications as to how that policy is working in practice.

Dr A. M. Ridley, Managing Director (Railways), London Transport

To what extent do the Authors believe that the success that was achieved was due to the single-mindedness of the team (not just the Corporation team, but all the people involved), and to what extent to the style of Hong Kong, the fact that we were all working in a rather unique place? How effective was it to have three separate teams under the Engineering and Project Director: the Engineer; a substantial number of engineers with delegated powers in a separate team; and a Commercial Department. How acceptable was this to the contractors?

32. The Mass Transit Railway Corporation administered the project in a fairly ruthless fashion. This was only possible because of the large amount of work that was carried out by the consultants, and indeed the Hong Kong Government, long before the Corporation team was set up. Could the Corporation have related differently to the consultants and to the contractors in any way to improve the manner in which the project was carried out?

Mr J. Gordon, Consulting Engineer

I note that the dredging of the trench for the cross-harbour section was carried out using clamshells. Bucket dredgers or large cutter suction dredgers might have given a more accurate profile and perhaps reduced the amount of fill material required. Were these considered? I would also like to know what type of material was dredged and what sort of accuracy was obtained.

Mr A. S. Angus, Mott, Hay & Anderson

Having been involved in the Hong Kong Mass Transit Railway project during the planning and tender stages, I have some knowledge of the complexity of the undertaking and would like to congratulate all concerned in its construction on their magnificent achievment.

35. During the tender discussions I was particularly interested in the different proposals put forward for tunnelling in non-cohesive water-bearing strata. The Engineer's assumptions, based on experience gained in the trial tunnels,[4] indicated a preference for the traditional UK method of driving in compressed air using a shield and bolted segmental linings. Many contractors, however, proposed to dispense with compressed air working as far as possible, and to rely on other techniques, such as deep well pumping and ground treatment, to control groundwater and stabilize the face. Many also favoured a more extensive use of in situ concrete tunnel lining.

36. In Paper 8391 (§ 6), the Authors state that the contractors' designs and construction methods generally followed those envisaged by the Engineer, but there appear to have been a few exceptions. Considerable settlement has taken place in some areas, mainly I suspect where the Engineer's scheme has been varied, and I would welcome further information on this point. Information regarding settlement in the Nathan Road section, particularly in the vicinity of the crossover tunnels, would also be appreciated. With the benefit of hindsight, do the Authors believe that the methods actually adopted were the most appropriate for the conditions?

37. With regard to compressed air working, I note that the overall bends rate as given in Tables 3 and 4 is considerably higher than that experienced during the construction of the Clyde tunnel[5] nearly 20 years ago. This may be because decompressions were carried out in accordance with different procedures, or, judging from the figures in Table 4, because not many Japanese were employed in the Clyde tunnel! Strangely enough, in Table 3 it is the Europeans who have the higher bends rate.

Mr D. F. Lilliman, Freeman Fox & Partners

For Kowloon Bay Depot, the large diameter bored piles were designed as end-bearing in crystalline rock. This meant that all piles had to penetrate the full thickness of superincumbent strata consisting of fill, marine sediments and decomposed granite; the latter containing boulders of hard sound granite, the frequency and size of which generally increased with depth.

39. There were difficulties therefore in properly identifying suitable found levels for the piles. These difficulties were heightened by the considerable variations in level of the general bedrock surface beneath the site.

40. The bedrock surface could be regarded as a broad flattish area surmounted by two knolls approximately 15 m high at the centre of the site, with dissections at the north and south ends by valleys of around 30 m deep. This 'ancient landscape' is very much like that which can be seen on erosional surfaces of granite exposed at the present day in Hong Kong.

41. The pre-contract site investigation, together with further site investigation carried out by the main contractor under his contract obligations, proved inadequate for the purposes of establishing pile toe levels with an appropriate degree of confidence. For this reason a considerable number of additional boreholes were sunk across the site.

42. On completion of the depot piled foundations, a series of control points was established for the purposes of monitoring settlements. I would like to know whether or not settlements were monitored during and after construction of the development works and, if so, how the observed settlements compared with the allowances made in the podium design calculations.

43. I would like to have the Authors' comments on the relative performances of the several quite different piling systems used both within the depot area and for the overhead viaduct structures, in relation to the ground conditions, which I assume were reasonably comparable.

Mr A. W. Shilston, Consulting Engineer

Within the British contractual repertoire this scheme was put together in a highly individualistic way and without precedent. One is surprised that the employing

authority ever seriously considered that the necessary degree of commitment to affect satisfactory performance would be achievable with a joint venture of 56 contractors,[6] even Japanese. Fortunately, in the event, the scheme was project-managed.

45. Non-British and particularly Japanese contractors find the Anglo-Saxon style of engineering contract, with an 'Engineer', exceptional whereas to the British it is the norm. Tendering British contractors, working within a contract which owed close allegiance to the FIDIC/ICE style of contract, found that they had an 'Engineer' but he was not responsible for the sufficiency of detailed design: that was their burden to carry and task to prepare. Further, they were required to bid on a lump sum contract basis to allow final price control to be exercised by the Employer.

46. Experience suggested that if large and complex construction contracts were let on a lump sum contract basis and detailed design proceeded in parallel with construction, particularly where the Contractor was responsible for design and the Employer wished to concern himself greatly with detailed design, either one was likely to end up with a major dispute or the form of contract would have to be changed during the progress of the work to enable performance to be achieved.

47. The Authors apparently are now involved in an extension of the Mass Transit Railway and the public advertisement thereon by the Employer, displayed in the national press on 5 January, 1981, stated that 'The Corporation will invite tenders for the construction of this extension on the basis of a number of separate contracts for the Civil, Electrical and Mechanical Works . . . Tenders, based upon designs prepared by the Corporation, will be invited from selected lists of prequalified contractors . . .'.

48. The preparation of contracts for the new work reasonably could be expected to reflect broad experience acquired from the earlier work. How did tenderers regard the original unusual form of contract devised to deal with the then urgent needs of the Employer? And in what respects has the form of contract changed for the new work? In particular, will there again be a standard contract to embrace civil, mechanical and electrical work?

49. Finally, referring to Fig. 19 of Paper 8389, why did the outcome of the Consultant's examination of contractors' permanent works design drawings have to be referred both to the Employer, an organ of Government, and the Government itself?

The Authors

In reply to the **Chairman**'s question on the recovery of capital costs out of revenue, it is confirmed that this is still the intention of the Corporation. At the moment, revenue is still below budget and below the forecasts which were made in 1975. These forecasts were rough and ready as there was no previous experience of opening up an underground system in an area such as Hong Kong. Revenue is rising steadily and should increase substantially in 1981, and it will certainly increase when the Tsuen Wan extension opens in 1982. It is anticipated that all borrowings should be paid off by about 1993.

51. **Dr Ridley** asks a difficult question. There was indeed a determined, single-minded team with a rarely encountered team spirit. Many nationalities were represented and the very great amount of enthusiasm could only have been engendered by the general bustle and activity of Hong Kong, where there is a

determination to get things done. Progress is not hindered by lengthy government enquiries but is assisted by full support and the overall intention that the MTR should make a contribution to the solution of Hong Kong's transport problems. It is unlikely that similar success could have been achieved in any environment other than Hong Kong, but to apportion the benefit between the single-mindedness of the team and the efforts of the people of Hong Kong is just not possible.

52. Having the three management teams worked out quite well and incorporated an element of controlled conflict. There were differences of opinion between those in engineering, those in construction and those in contract administration. The problems were faced up to and the system worked well. The same system, with very little change, is being adopted for the Tsuen Wan extension and there is no reason why it should not also be used on the Island Line when approval is granted.

53. We agree with **Mr Harris** concerning the hand-dug caissons and were initially appalled by the apparent risks that labourers were taking. Apart from the question of safety, the quite dreadful conditions of wetness and the eventual breaking out to be done in rock would certainly not be tolerated by UK labour. There is, of course, a much greater supply of labour in Hong Kong and the system is popular with contractors as it is easier to mobilize many more teams for the work than it is to mobilize plant. More sophisticated techniques and greater mechanization will probably lead to it being less popular in the future. There are not many accidents apart from the rather obvious one of people tending to fall down open or unprotected holes. This may be due to it being essentially a family operation in which the man at the bottom is protected by his family at the top. Also, the families involved have very great experience of the work and know what they can do and what they can get away with.

54. Because of differential movement the building housing the Courts of Justice cracked across the weak axis which was parallel to Chater Road, resulting in some very rapid consultation between the Corporation and the Government. It would have been imprudent to have guaranteed that the normal activities of the Courts of Justice could continue while construction continued, so the Courts were evacuated. For the diaphragm wall at Swire House, Ove Arup introduced a requirement for heavier-density bentonite at a greater head, together with dewatering wells. They also proposed the use of recharged wells at the Courts of Justice and these were very successful. It is confirmed, in reply to **Mr Dawkins**, that settlement did go up to as much as 150 mm. The original 90 mm took place during diaphragm wall construction, and the further 60 mm took place following the installation of the diaphragm walls during excavation and generally as a result of wall flexing and, to a small extent, dewatering because of the recharge measures that were adopted. The Courts of Justice are at present unoccupied.

55. Replying to **Mr Lance**, the shape of the tunnel linings was maintained extremely well with nothing other than chogging off the ground behind the rings—with neither extra strutting nor tie bars. They were built two rings at a time, each ring being 600 mm wide and with a diameter of around 10 m, and they were generally within 25 mm on any diameter. Four lasers were used for setting out and considerable survey effort was put into getting the shape right. Progress started at two rings per week, rapidly went to four, and quite regularly six were achieved. At one stage, seven rings were achieved for several weeks.

56. Settlement throughout the whole of contract 107 was extremely low, being of the order of 25 mm, except in areas where difficult ground was met. This

included the crossover areas which at times would have twin 5 m tunnels going through the same area of ground. Pressure in the northern crossover was around 2·2 bar in order fully to balance the hydrostatic head for most of the time. The grouting was also good and both these factors probably assisted in keeping settlement to a minimum.

57. In reply to **Mr Gordon**, clamshell dredgers were used for the cross-harbour tunnel trench not only because they were available but because their operators were accustomed to manoeuvring in the sea-going traffic. The distance to dumping grounds prohibited the use of pipelines and the clamshell arrangement with local barges was more economical to operate. In certain parts of the trench a high content of large boulders was found and these had to be pre-blasted and broken before they could be handled even with clamshells.

58. Replying to **Mr Kibblewhite**, the plinths had to be kept small in cross-sectional area in order to reduce the amount of concrete as this was to be handled through a contract which had a very short construction time allocated to it. There had to be enough concrete for the top surface to be finished to a very precise line and level. This also meant that a large amount of reinforcement had to be put into the plinth to maintain the structural strength. The longitudinal reinforcement is a problem where electrical engineers are concerned as it provides the alternative current path. Plastic clips were used to separate electrically the longitudinal and the transverse steel. However, more than 100 000 Pandrol clips were located within and very near to the steel reinforcement and, with this large number, obviously some would have been misplaced during concreting, leading to a degree of failure to achieve the ideal. It has been suggested that the Pandrol clips could be glued into holes as was done on the flat slabs for the points and crossings, with the glue providing insulation. This would not wholly solve the problem of the longitudinal reinforcement because again, it is very difficult to keep it clear. A larger cross-section with less reinforcement might be used but there is no simple solution. One of the remedial measures adopted is the installation of 'top hat' insulation in long stretches of the track. This uses the normal width resilient pad but has a wider layer of neoprene on top of it in order to increase the leakage path. Measurements have indicated that this greatly improves the situation but it is not certain that the solution is a final one.

59. In reply to **Mr Angus**, the areas where greater than normally acceptable settlement occurred corresponded in the main to those where the contractors' alternative tunnelling methods with in situ rather than segmental linings were used. These alternatives were approved where such settlement could be accommodated.

60. On contract 201 the new modified Austrian tunnelling method was used in conjunction with dewatering. For contract 203, rock tunnel support methods were used with in situ concrete lining in conjunction with compressed air working. Excessive air losses were considered to be the main cause of settlement.

61. The Engineer's design concept of segmentally lined tunnels was followed on contract 107, which included the three large diameter crossover tunnels. Here and on contract 109 the settlement was minimal.

62. The bends rate for the Clyde tunnel in the range 2·04–2·40 bar was 0·918% and for contract 107 in the range 2·04–2·58 bar it was 1·007%: at these critical higher pressures the difference in bends rate is thus insignificant. Also, 59% of the total decompressions on contract 107 were carried out in the higher range as against only 4% at Clyde. Another factor which could have adversely affected the

results on contract 107 was that the high and low level compressed air work was carried out at the same time from one site. Supervisory staff and labour moving between the workings could not become acclimatized to a particular pressure. This would have affected the European supervisory staff and pit bosses and may account for the higher bends rates noted by Mr Angus. Europeans could also have suffered from lack of acclimatization to Hong Kong conditions.

63. In reply to **Mr Lilliman**, settlements which were monitored until completion of the podium were in line with predicted values. Concerning piling systems, at the podium at the depot large diameter piles were installed to establish that true founding had been attained and numerous exploratory boreholes became necessary. Elsewhere in the depot and for the viaducts 60 mm Frankipiles or steel H-piles, driven to set or to rock, were used. Boulders were again a problem, requiring frequent re-driving to avoid them. Recourse was made to hand-dug large diameter pile shafts where the number of boulders was excessive but these were of limited use in the presence of great rock depth and high groundwater level. Figures of settlement during development works are not available as the reference points became inaccessible.

64. Turning to **Mr Shilston**'s question, our Papers dealt with the first line—the Modified Initial System—and not the extension to which he refers. It would therefore be inappropriate to deal fully with the conditions of contract for the extension. Some aspects are, however, relevant to the MIS conditions. Changes have been made because the civil contracts are being let on the basis of full working drawings being prepared by the 'Engineer' (in fact by the Consulting Engineer appointed by the Employer). Basically the conditions of contract prepared for the MIS were found to be satisfactory by both parties and did not lead to an abnormal number of disputes; those that did arise were settled without undue difficulty.

65. Mr Shilston's question relating to Fig. 19 of Paper 8389 poses a problem which exists only because of his emotive reference to the Mass Transit Railway Corporation as 'an organ of Government'. The Corporation is an independent public body whose shares, at present, are held by the Government. Its organization and responsibilities are therefore wholly outside those appertaining to the Government. Thus it is necessary to refer design drawings to the Corporation for them to consider aspects relating to the construction and operation of the MTR. The relevant Government Departments have to comment on the aspects affecting highways, housing, markets, hawkers' rights etc., which are their responsibility.

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