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Hong Kong Mass Transit Railway Modified Initial System: design and construction of above-ground works and trackwork

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The first part of the Paper describes the basis of selection of the type of structure for the viaducts of the elevated section of the railway, some of the problems encountered and the design and construction solutions adopted. Likewise the design and construction of the stations on the elevated section are discussed. The second part of the Paper is concerned with the design and construction of the depot and particularly of the development above. This development comprises a 10 ha podium with blocks of residential flats above to house 25 000 people, and a full range of commercial and recreational facilities to cater for the surrounding area. Finally the Paper describes the design and construction of the track support system.

Design and construction of above-ground stations and viaducts

The overhead works of the railway are situated at the north-east end of the Modified Initial System (MIS) in the Kwun Tong district of Kowloon. The area is bisected by Kwun Tong Road, its principal road artery, along which the elevated structures of the railway are located. To the south of Kwun Tong Road are mainly industrial buildings; to the north are several major Government housing estates. There are three overhead stations: Kowloon Bay, Ngau Tau Kok and the terminus of the MIS, Kwun Tong.

Design of overhead viaduct structures

2. The route of the overhead section requires three crossings of Kwun Tong Road, a dual three-lane highway, with all sections of the alignment either directly alongside or supported from the centre of the road.

3. Ground conditions consist mainly of marine deposits and colluvium overlying completely weathered granite grading into fresh granite. The depth of the

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fresh granite varies considerably, with some sections of the works founded directly on the rock, but most requiring extensive piling.

4. The siting of the viaduct piers to avoid major road or utility diversions was a primary objective. An analysis of the possible positions for the viaduct columns indicated that a structural form capable of economical spans in the 25–32 m range was desirable, with a limited number of spans of up to 52 m at the major road crossings.

5. The objective was to create a viaduct form that achieved a unity of appearance, without abrupt changes of form between successive sections. As the continuously welded trackwork was to be fixed directly to the structure, structural expansion joints had to be minimized. This dictated a viaduct form employing continuous spans (Fig. 1).

6. An investigation of alternative structural forms indicated that a prestressed concrete box section, 1·6 m in depth, achieved the design objectives with the greatest economy. The basic section was modified for the longer spans either by tapering the end spans to a greater depth which was then maintained over the long spans, or by

Table 1. Viaduct data (down track only)

Contract	Section	Continuous length, m	Spans, m	Box type	Box depth, m
210	A	45	22–21	Standard	1·6
	B	200	20–52–33–52–30	Haunched	1·6 to 2·5 over internal piers
	C	154	20–4 × 28–19	Standard	1·6
	Kowloon Bay station	219	—	—	—
	D (2 sections)	416	22–31–19–2 × 26–28–2 × 30–25–5 × 30–25	Standard	1·6
211	E (mainline)	76	21–31–22·5	Standard	1·6
	E (siding)	76	21–31–22·5	Multicell	1·6
	F (mainline)	328	28–40–2 × 43–4 × 37–27	Multicell	2·0 tapered to 1·6 at end piers
	F (highway)*	307	30–2 × 43–4 × 37–28	Trapezoidal	2·2 tapered to 1·5 over end piers
	G	117	18–2 × 27–26–17	Standard	1·6
	Ngau Tau Kok station	219	—	—	—
	H	101	20–24–2 × 26	Standard	1·6
	I†	158	35–2 × 45–31	Single	2·0 tapered to 1·6 over end piers
	J	235	26–3 × 30–32–2 × 30–25	Multicell	1·6
212	K	169	20–30–32–2 × 30–23	Multicell	1·6
	Kwun Tong station	186	—	—	—
	L	129	29–2 × 32–31	Multicell	1·6

*Seven supports of section F are transverse prestressed beams spanning roadways, supporting both viaducts.

†Two supports of section I are prestressed transverse beams spanning the roadway.

adding haunched sections over the intermediate columns (Fig. 2). A span by span construction technique was used, with the prestressing cables of a given span coupled to, or overlapped with, the cables in the previous span.

7. Table 1 sets out the different sections of continuous viaduct and lists the spans and form of structure used. Sections B, F and I involved the three heavily skewed crossings of Kwun Tong Road. Sections F and I were such that normal column support could not be provided and transverse prestressed beams span the carriageways to columns on either side. Moreover, the transverse beams of section F carry, as well as the railway, a parallel three-lane highway structure. This Public Works Department structure was incorporated in the MTR contract as a matter of convenience.

8. Precast concrete parapets, with a prominent ribbed finish, help to provide a unity of appearance in the structures. The function of the parapets is to carry the trackside cables and to contain noise and spray. Precast concrete units are set into the parapet line at intervals to support the steel masts of the overhead electrification system.

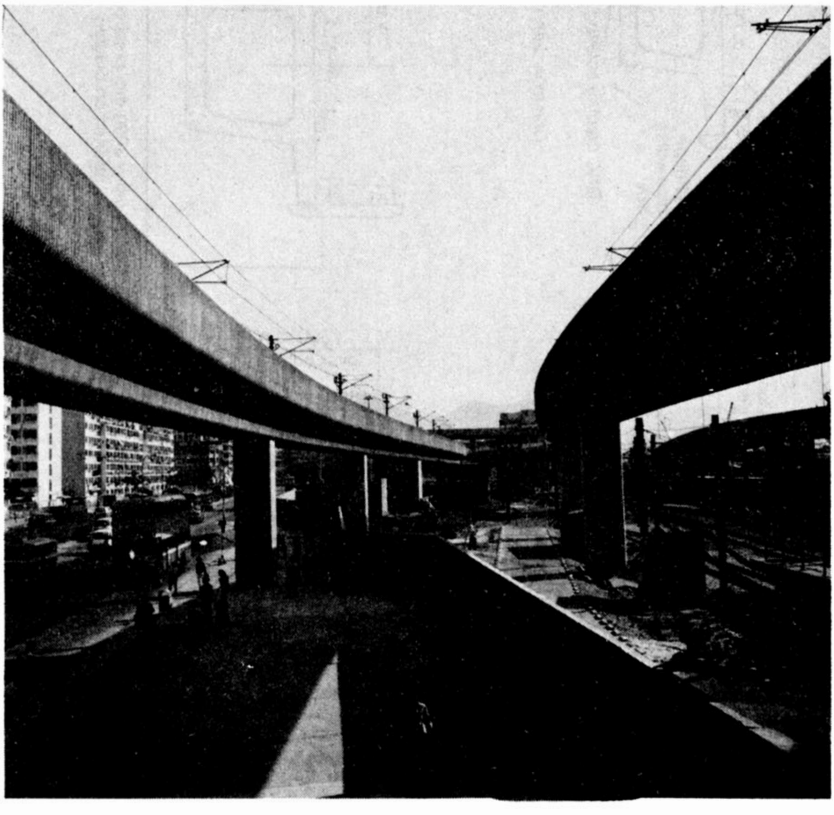


Fig. 1. Typical standard section viaduct

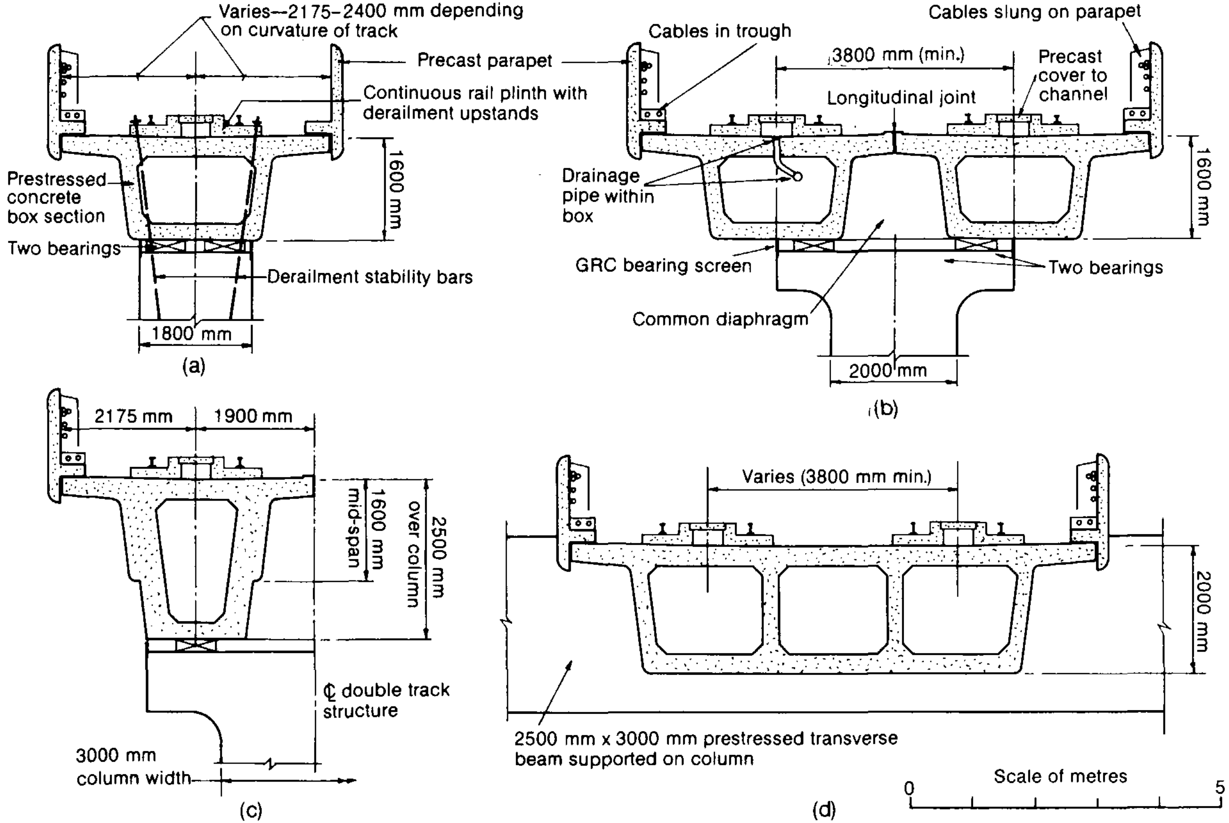


Fig. 2. Typical viaduct sections: (a) standard single-track box and column; (b) standard double-track boxes and column; (c) section B—haunch added to achieve 52 m span; (d) sections F and I—2 m deep multicell box on transverse prestressed beams; maximum span 44 m

9. The articulation of the viaducts is such that bearings at all columns permit longitudinal sliding except at one anchor column in each section.

10. Raised concrete kerbs between the rails are designed to contain derailments. Where a derailment is not totally contained by these kerbs, severe uplift forces could be imposed at the bearings on single track columns. Stability is ensured by the provision of vertical prestressing bars in grease-filled oval ducts to permit longitudinal viaduct movements.

Construction of viaducts

11. *Contract 210.* Three factors influenced the contractor in his choice of viaduct falsework: the large number of standard viaduct spans; the possibility of settlement of recently reclaimed land; and the need for early completion of the viaducts and station.

12. The chosen solution was to employ a falsework system of prefabricated steel trusses supporting steel formwork panels. The trusses consisted of a fixed span length, to suit the shortest span, with a series of 'bolt on' extension pieces to achieve longer spans. The trusses were supported by the column foundations and an intermediate tower on a spread footing which incorporated a jacking facility to adjust for settlement during concreting. Each truss was erected by a mobile crane. The formwork units rested on cross-beams supported by screwjacks on the trusses (Fig. 3).

13. When the formwork was struck, the exterior units were removed by a mobile crane after the screw jacks had first been lowered. Temporary cross-beams were then inserted under the truss ends and attached to Tirfor winches at deck level. These took the weight of the trusses while the falsework towers were dismantled, and were then used to lower the trusses directly onto flat-bed lorries for movement to the next span.

14. Each span of the viaduct was cast in two sections—bottom flange and webs, followed by top flange and diaphragms—in order to minimize stresses induced by deflexion of the trusses. Sufficient sets of falsework were provided to enable the casting of complete spans, less a gap at the coupler point, to be carried out well in advance of the stressing operation. Cycle time was therefore governed only by the period necessary to install the couplers and to obtain transfer strength in the concrete infill to the gap.

15. *Section F of contract 211.* Section F consists of two parallel multicelled prestressed box structures, one supporting the railway and the other an elevated road. The dominant problem was that both structures shared common supporting beams over Kwun Tong Road, on which road traffic had to be maintained at all times. Since the cross-beams were monolithic with the viaducts, it was necessary that parallel sections of both viaducts be cast and stressed simultaneously, span by span. The cross-beams were cast and 50% stressed in advance, stressing being completed after the stressing of the viaducts.

16. A sequence of road diversions was carefully planned so that, as far as possible, traffic was diverted away from the section of viaduct currently under construction. However, on one section this was not possible and the railway viaduct had to be constructed while traffic still used the road below. The contractor achieved this by spanning the roadway with 13 m long universal beams, resting on Acrow Hiload falsework frames. The beams were erected and dismantled during temporary road closures in the early hours of the morning (Fig. 4).

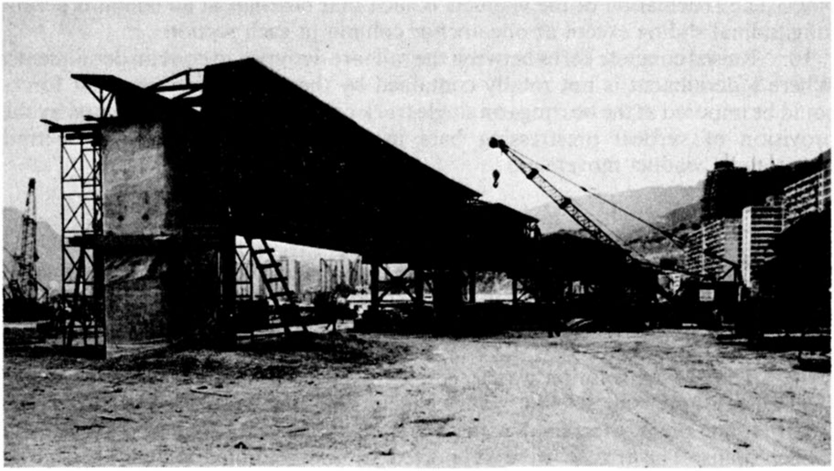


Fig. 3. Falsework trusses on contract 210

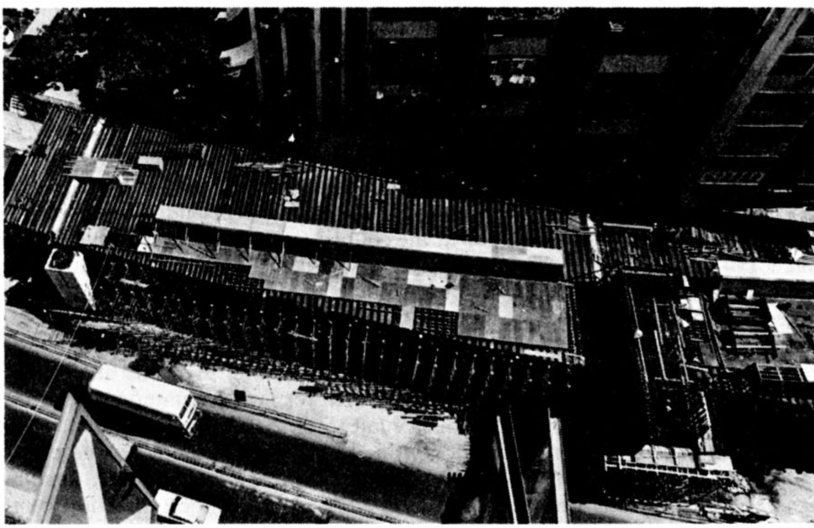


Fig. 4. Falsework on section F

Design of overhead stations

17. Although the three above-ground stations, Kowloon Bay, Ngau Tau Kok and Kwun Tong, have considerably different site conditions, the objective was to provide as many unifying features as possible. All stations have island platforms, sheltered by a reinforced concrete canopy which cantilevers over the tracks from

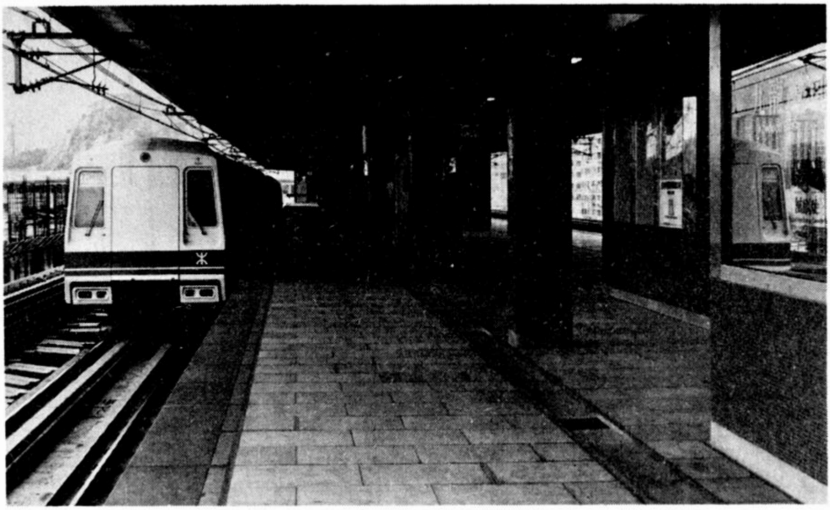


Fig. 5. Kowloon Bay station: platform and canopy

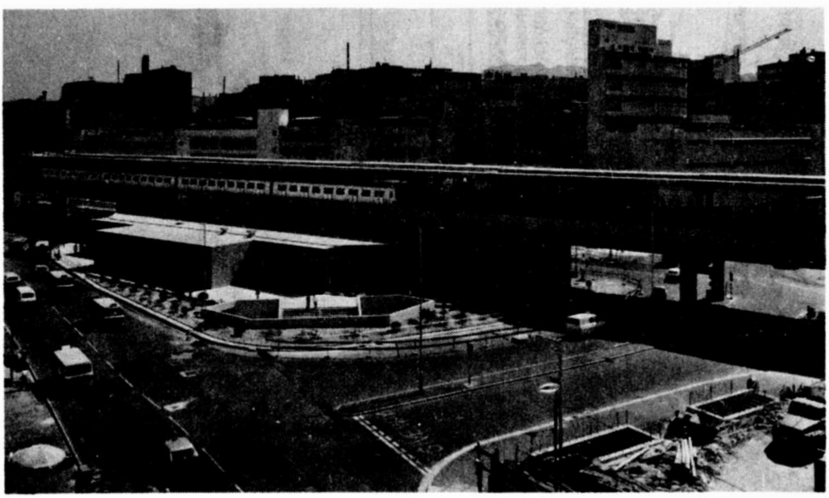


Fig. 6. Ngau Tau Kok station

columns located within the central zone of the platform. Escalators, an auxiliary staircase and cash lift connect the platforms to the concourse beneath on which are ticket machines, entrance and exit gates, and the station offices. At the platform ends there are rooms for the station electrical equipment and signalling relays.

18. The structural arrangement for the stations is a monolithic frame of

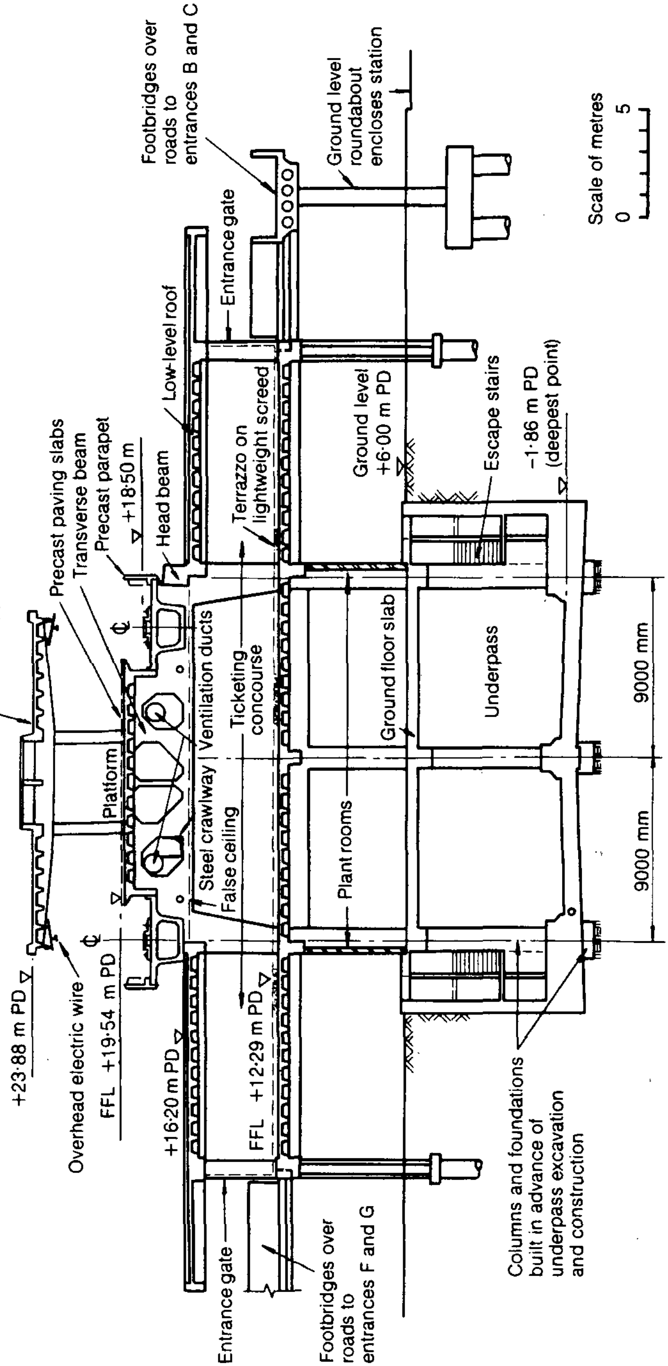


Fig. 7. Section through central part of Kwun Tong station

reinforced concrete. A grid to suit each site layout was chosen: 10·5 m at Kowloon Bay, 11·98 m at Ngau Tau Kok, and 11·22 m at Kwun Tong. To provide unity of appearance with the viaducts the station track beams have an identical depth and appearance and support the same precast parapets on their outside edge.

19. At Kowloon Bay and Ngau Tau Kok, the main columns are located on the track beam centre-lines and support deep transverse beams, spanning the concourse area, which carry the platform structure and the roof canopy columns (Fig. 5). The transverse beams are pierced by large openings to permit the passage of air ducts and cableways along the length of the station.

20. *Kowloon Bay station.* Kowloon Bay has a full length concourse at first floor level connected at either end directly to footbridges over Kwun Tong Road and to the Telford Gardens development over Kowloon Bay Depot. Construction was entirely orthodox, employing for the most part timber falsework and formwork. Reusable glassfibre moulds were used for the waffle slabs employed for the concourse floor.

21. *Ngau Tau Kok station.* Ngau Tau Kok has a ground-level concourse within the central portion of the station, but the platforms extend at either end over a road junction and a bus station (Fig. 6). These ground-level features require a double-span spacing for the columns and over these lengths the platform and track beams are prestressed. Access to the station is by subways beneath the adjoining roads. The transverse beams and portal structures were cast in advance of the remainder of the platform structure. The outer prestressed sections were cast on longitudinal steel beams, spanning the existing road system, as these four- and two-span sections were each stressed in a single operation.

22. The programme dictated that it was necessary to install the tracks through the station while the roof canopy was still under construction. The contractor achieved this by means of props, which were located just clear of the gauge required for passage of the track-laying works train and which supported steel beams cantilevered out over the track. These beams supported the formwork for casting the roof canopy. Fibreglass moulds were used for the troughed section employed for the roof canopy and also for the waffle slabs used elsewhere in the station.

23. *Kwun Tong station.* Kwun Tong station is particularly complex, in that it has a vehicular underpass running beneath its longitudinal axis. The underpass has dual carriageways with the station columns springing from the retaining walls and the median strip. The underpass is enclosed over its deepest section by a ground-level slab which supports station plantrooms within a roundabout forming part of the ground-level road system. The concourse extends the full length of the station, spanning the roundabout carriageways, with double-grid, precast, prestressed concrete I beams supporting a monolithic slab (Fig. 7). The concourse is extended within the roundabout with an extensive system of reinforced footbridges connecting across the surrounding roads.

24. The alignment of the tracks is dictated by the railway crossover on the approach to the station. The track alignment does not relate to the setting out of the columns, which is determined by the underpass. To make matters more complicated still the underpass and the whole site of the station is on a curve of about 1000 m radius. All this resulted in considerable structural and setting-out complication.

25. The construction programme for the MTR did not allow a normal sequential construction for the underpass followed by the station superstructure. Steel sheetpiles were first driven along the underpass perimeter and the station

columns were constructed down to the level of the underpass inside circular hand-dug caissons with provision for future connection to the underpass structure. The ground-level slab was cast on top of the columns on formwork resting on the original ground level prior to the excavation of the underpass. Subsequently, the ground was removed between the sheet-piled walls beneath the ground-level slab, with temporary steel propping employed until the underpass roadway and retaining walls were completed.

26. Completion of the ground slabs over the underpass enabled circulating traffic to be established on the permanent roundabout bridges, thus ending the previous severance of the site. Prior to this diversion, the precast prestressed beams spanning the double bay sections at concourse level were placed, thereby creating a continuous area of concourse floor over the station length for the assembly, storage and movement of materials for the station construction.

27. Materials were handled primarily by a tower crane sited within the roundabout area, which covered the central section of the station. The southern section was served by a second tower crane located between the divided structures of adjacent viaduct sections, whereas the shorter northern section was served by a mobile crane. The platform structure was built on an alternate bay sequence, materials being handled firstly at concourse level between sections under construction and then switched to the completed platform areas. Transverse beams were cast in advance of the main platform structure.

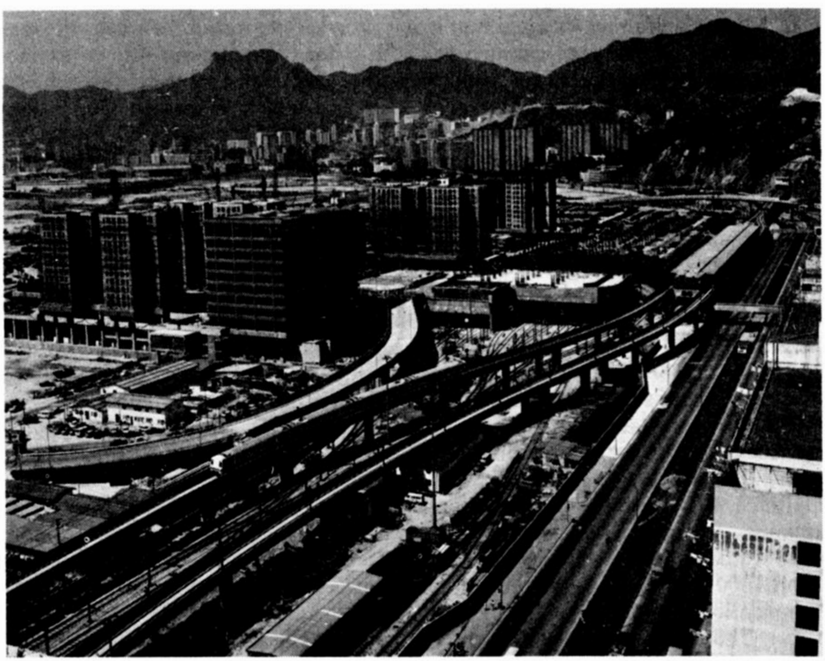


Fig. 8. Kowloon Bay Depot: view from south

28. As at Ngau Tau Kok, the roof canopy was cast on a system of steel beams cantilevered over the tracks. This was to enable the trackwork contractor to install the tracks while the roof was still under construction.

Design and construction of the depot

Historical background

29. The MIS depot is sited on 16·5 ha of reclaimed land adjacent to the airport runway at Kowloon Bay (Figs 8 and 9). The depot is the nerve-centre of the system and contains the control rooms, substations, training school, workshops, maintenance bays and stabling for 32 eight-car trainsets. In the area of the track fans are the control tower, car-washing plants, stormwater and sewage pumping stations and the permanent way workshop (Fig. 10).

30. Until 1975, a single-storeyed north light workshop and maintenance building was planned. There was to be a separate administration building and open stabling. Rapidly increasing land values, however, led to a late decision to develop above the depot. The roof of the workshop and maintenance building was therefore redesigned as a concrete slab and was extended to cover the stabling sidings and other areas. It became known as the podium and covered a total area of 10 ha. Up to seven levels of commercial development, and the administration building, were planned over the podium, together with residential blocks to house 25 000 people

Fig. 9. Kowloon Bay Depot: north fan

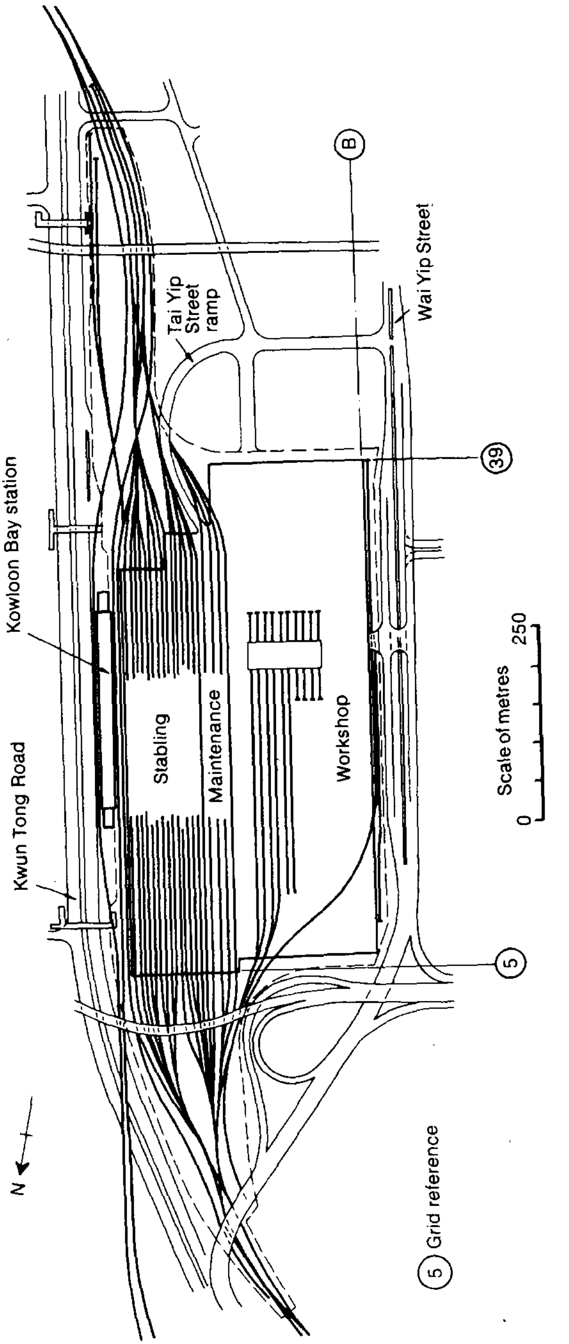


Fig. 10. Kowloon Bay Depot: general layout

Table 2. Responsibilities of designers of podium and development

Podium structure
Main consultants – Freeman Fox & Partners (Far East)
Commercial development
Architects – Palmer & Turner
Structural engineers – Freeman Fox & Partners (Far East)
Residential development
Architects – Hsin Tieh & Associates
Structural Engineers – Gordon Wu & Associates in association with Ove Arup & Partners
Overall structural check
Structural engineers – Freeman Fox & Partners (Far East)

over the commercial levels. The depot column grid, generally 14 m by 14 m, was maintained.

31. The Corporation formed a joint venture with a developer who was free to design the residential blocks within certain restraints. This required a high degree of co-operation between the designers, whose responsibilities were as shown in Table 2.

32. The developer's consultants decided on 'transfer plates' which were in fact deep grillages below the residential blocks, to overcome the problems set by the very wide railway column grid. An overall height restriction, imposed by the proximity of the airport, led to the need to minimize clearances under the podium. Headrooms of 9 m in the workshops and 6·6 m in the stabling sidings were required to satisfy working and ventilation requirements.

Design of the depot podium

33. The Building Ordinance contains stringent statutory requirements covering the design and construction of all private buildings. The Building Construction Regulations are based on the old GLC bylaws, partially modified in accordance with CP 114.

34. The site is on reclaimed land with ground level at approximately +5 m PD (Principal Datum) and the water table some 3 m lower. Fill materials of depth from 5–13 m overlie 4–15 m of marine deposits and up to 16 m of completely weathered granite (CWG). The bedrock level varies between −20 m PD and −65 m PD, with boulders commonly found in the CWG near the interface.

35. The podium structure itself is supported by 2209 large diameter bored piles, while 644 steel H section driven piles support the access ramps, footbridges and elevated roadway. The bored piles vary in size from 1000 mm to 1500 mm dia. and were constructed using the reverse circulation rotary drilling method (RCD); lengths vary between 20 m and 65 m with a mean length of 34 m. The piles were designed as end bearing in crystalline rock with a capacity of 533 t/m^2 and allowance was made for negative skin friction from possible settlement of the fill materials. The H piles were driven to a predetermined set in the CWG.

36. Suspended ground-floor structures have been used in the workshops (Fig. 11), maintenance areas, stores, substation and training school (Fig. 12) where substantial differential settlements could not be accepted. In these areas reinforced

concrete (r.c.) ground beams connect the columns and support the r.c. beam and slab structure, while r.c. tie beams connect the pile caps in the other areas. The design loads for the suspended floors varied according to the use of the area. Live loads were 7·5–25 kN/m^2 and where appropriate the 'design train' load was applied. All areas are checked locally for the passage of a heavy vehicle (Fig. 13).

37. The 100 000 m^2 area of the podium is divided into 23 areas (Fig. 14), the largest being 98 m by 84 m. It is supported by over 1000 r.c. columns, varying in size from 1 m × 1 m to 4 m × 1·2 m, with a maximum height above pile cap of 11 m. The areas are divided by 40 mm wide, waterproofed, expansion joints which in the east–west direction are formed by the use of split columns and in the north–south direction by corbels with bearings.

38. The podium deck, which comprises a 175 mm slab spanning north–south on to 1000 mm deep ribs at 3·5 m centres, with 1150–1500 mm deep haunched main beams at 14 m centres, has been designed for superimposed loads of 7·5 kN/m^2 live

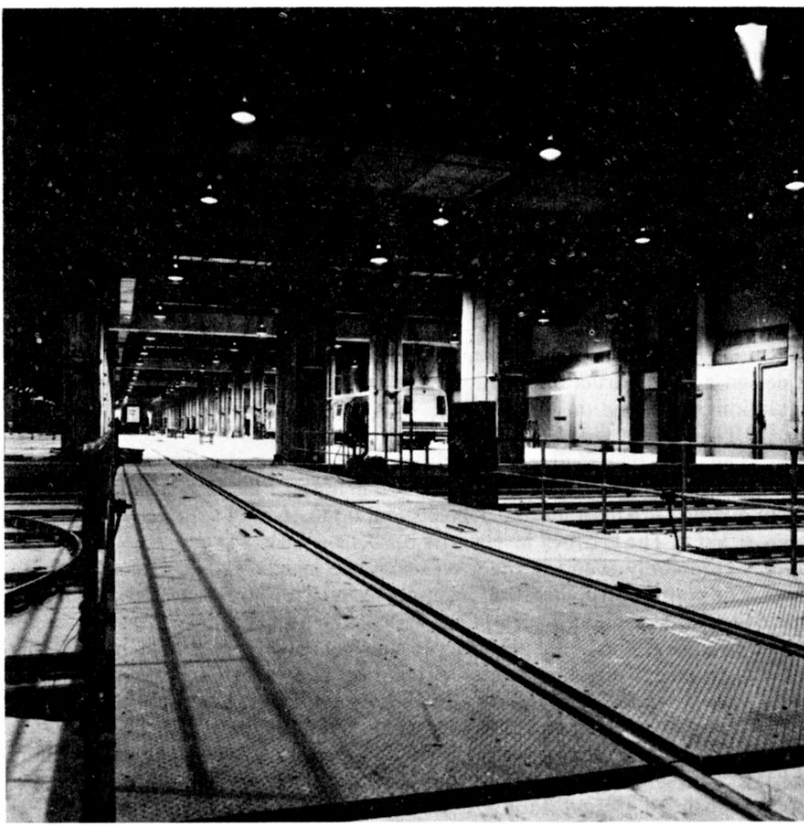


Fig. 11. Kowloon Bay Depot: traverser and workshop

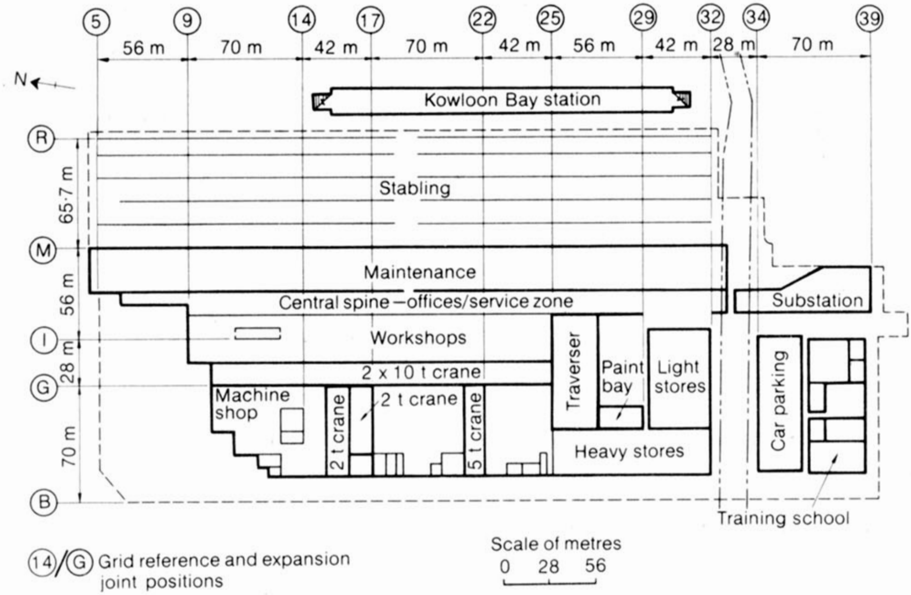


Fig. 12. Kowloon Bay Depot: ground floor layout

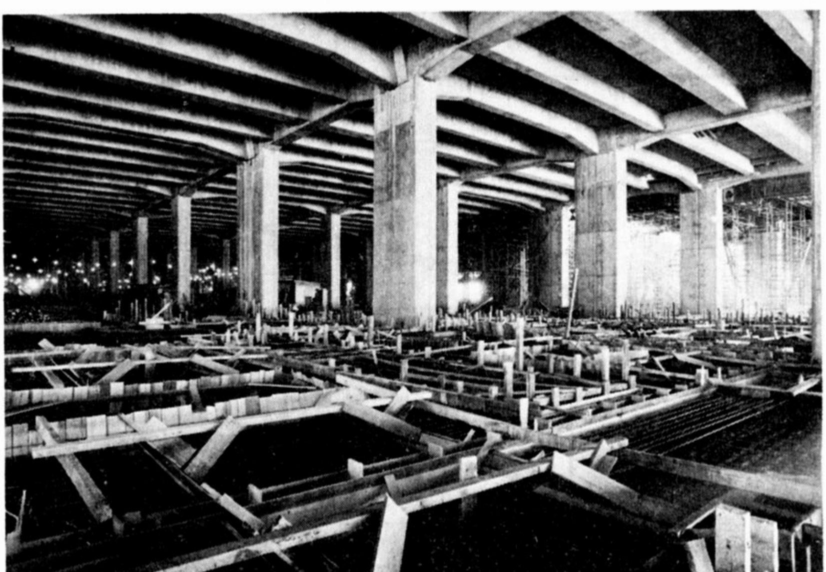


Fig. 13. Kowloon Bay Depot: floor construction

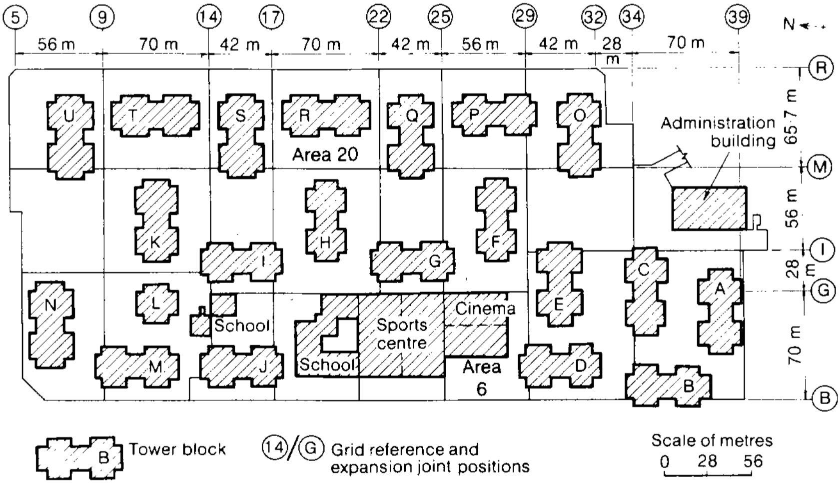


Fig. 14. Kowloon Bay Depot: podium roof plan

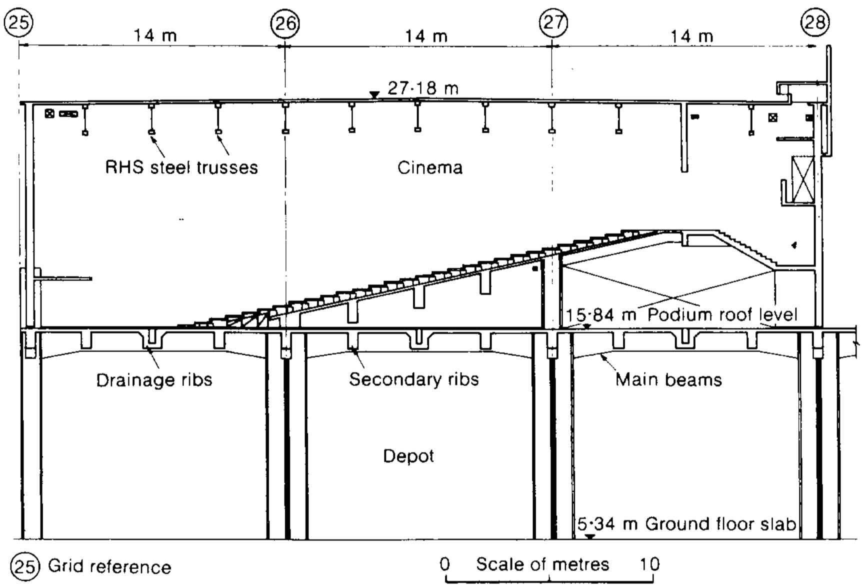


Fig. 15. Kowloon Bay Depot: section through area 6

and 3·0 kN/m^2 dead (Figs 15 and 16). Specific areas are designed as roadways or access routes with allowance for HA or 80% HA loading.

39. In the early stages of the design many simplifying assumptions, which later needed reviewing and checking, were made in order to progress the depot construction. As the planning progressed combined analyses were carried out with

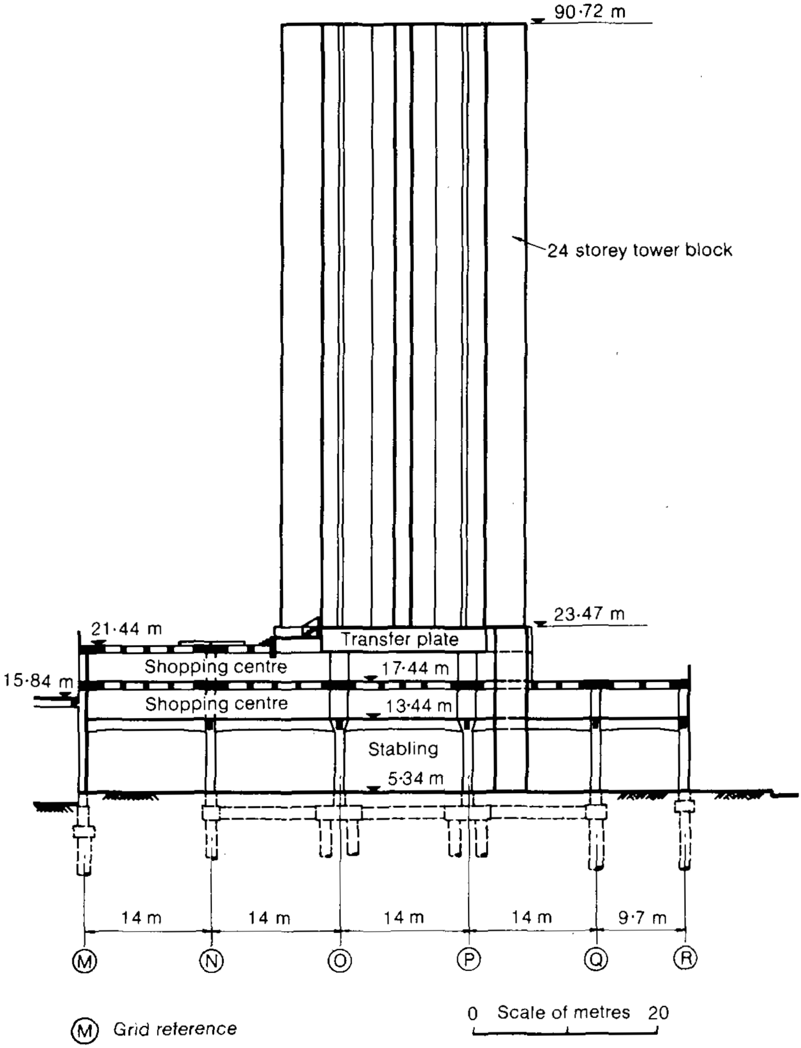
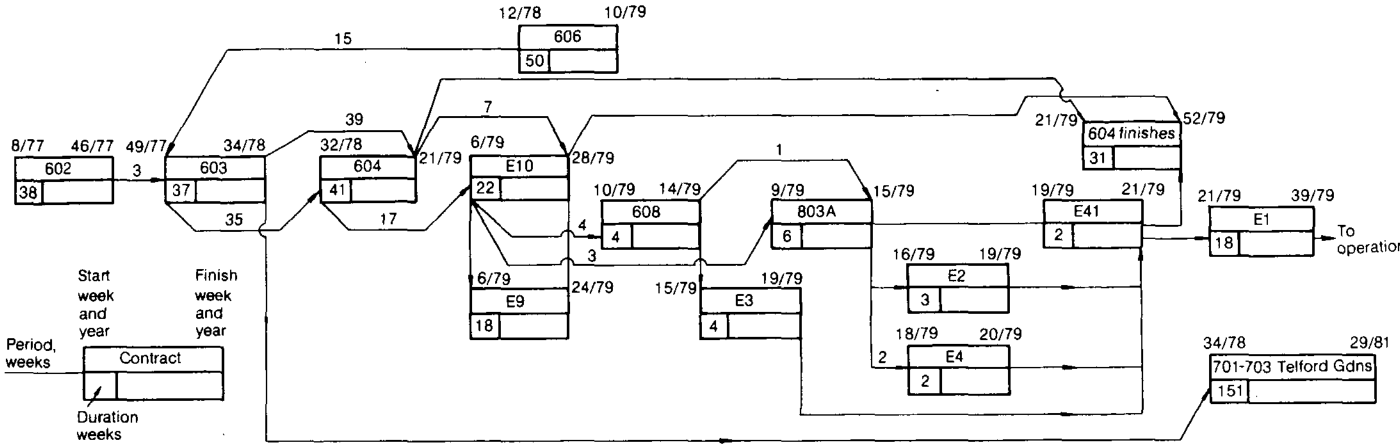


Fig. 16. Kowloon Bay Depot: section through area 20



602	Piling, pile caps and tie beams	E10	Kowloon Bay Depot E&M services
603	Earthwork, podium slab, ramps, pumping station and service tunnels	*E41*	*Overhead current supply system*
604	Civil builders and architectural works	608	Fire-protection material
E1	Electric multiple unit trains	803A	Tracklaying
E2	Signalling and control systems	701	Development: phase I walkways
E4	Telecommunications	702	Development: phase I columns and phase II columns and walkways
E6	*Power supply*	703	Development: phase III transfer plates, commercials and finishes
E9	Kowloon Bay Depot equipment	606	Administration building

Fig. 17. Kowloon Bay Depot: typical sequence of work

each consultant modelling sufficient of the interface structures to allow comprehensive checking of the designs from the various approaches.

40. Kowloon Bay Depot was one of the first property developments over industrial premises in Hong Kong. Special provisions had therefore to be agreed for the depot with the Fire Services Department and the Building Authority for fire protection, means of escape, and smoke extraction. The fire requirements specified that the podium should form a 4 h barrier and be capable of withstanding a complete 'burn out' in the depot without causing alarm or necessitating evacuation of the commercial areas above the podium. No penetrations by services could be allowed through the slab without complete fireproofing of the droppers or risers. Horizontal service runs for storm and foul water were introduced above the soffit, but within the slab, by the use of U shaped ribs with holes through the main beams which minimized penetration.

41. Large areas of vermiculite-based insulation have been sprayed on the soffit of the structure to limit heat flow in the event of fire. Expansion joints have been protected using Durasteel horizontally on slabs, and steel plates vertically on columns, to allow full closure of the joints in the extreme fire situation.

42. An overall structural check was carried out to ensure compatibility of the individual structures. Often podium construction preceded finalization of the designs of the structure above, and so the design of the podium had to be based on assumptions. It was also necessary to ensure that designs prepared by the different consultants were compatible with each other. An overall structural check was carried out therefore in which analyses of the combined structures enabled the separate approaches to be verified.

Commercial development and infrastructure

43. There are two separate vehicle access systems to the podium, one being a curved continuous prestressed concrete structure with a two-lane carriageway, the other an elevated interchange above an existing dual carriageway to which it is connected by four continuous prestressed concrete ramps. The ramps are generally of 28 m span except for one section over an adjoining road where the span is increased to 52 m with 37 m side spans. Two prestressed concrete footbridges provide pedestrian access to the west side of the podium, while on the east side, stairs and escalators give access to the concourse level of Kowloon Bay station and thence to ground level.

44. All necessary commercial facilities will be provided on the podium for the integrated 'township' of 25 000 residents. These facilities, which are also aimed at attracting over 150 000 customers from neighbouring developments, include restaurants, supermarkets, department stores, banks and a market; together with three schools, two cinemas, an amusement centre, a sports centre, an Olympic-sized swimming pool, vehicle parking and a bus terminus.

Programme

45. The sequence and timing of the award of the 16 separate main contracts involved in the construction of the depot and development was carried out to a master programme. The construction was phased, with each main contractor given sole possession at any one time of a geographical area.

46. Major delays on site caused the progress and programmes of the interfacing

contractors to be reviewed against a 'strategic plan', which included absolute minimum requirements for phased beneficial occupation of areas, to allow

(*a*) trial running to commence on schedule;
(*b*) completion of the workshops prior to passenger running;
(*c*) total completion of the podium, by areas, to allow phased occupation above.

Co-ordinated programmes (Fig. 17), based on the objectives of the strategic plan and discussions with the major contractors, were then produced. Progress was closely monitored against these programmes so that early action could be taken to ensure that targets were met.

Table 3. Track alignment standards

Horizontal curve radius:	
desirable minimum	350 m
absolute minimum in running lines	200 m
absolute minimum in depots	140 m
absolute minimum in stations	1000 m
Vertical curve radius:	
desirable minimum	3000 m
minimum (near stations only)	1500 m
Gradients:	
absolute maximum	3·0%
minimum (for drainage)	0·3%
at platforms in stations	Level
Cant:	
desirable maximum	130 mm
absolute maximum	150 mm
Cant deficiency maximum	110 mm

Table 4. Track-laying tolerances

Tolerances for track-laying:	
designed alignment	±5 mm Rate of variation less than 3 mm in 3 m or 8 mm in 15 m
cross level	±3 mm Rate of variation less than 3 mm in 3 m or 8 mm in 15 m
gauge	±1·5 mm Rate of variation less than 3 mm in 3 m
Tolerances for plinth construction:	
inclination of rail seat	1:20 designed 1:18 max. } as built 1:22 min. }
longitudinal vertical undulation	±1·5 mm on 1·5 m base

Construction

47. The major depot civil contracts were

contract 602—piling and pile caps
contract 603—columns and podium roof
contract 604—ground floor and site works

48. On completion of the contract 602 works in each area, the contract 603 contractor proceeded immediately with single-lift column casting. Due to the low bearing capacity of the reclaimed land, the podium roof falseworks were generally supported by steel castellated beams spanning between the columns assisted by struts raking from the quarter points back to the column bases (Fig. 18).

49. Construction above the podium was constrained by the loading restrictions of the podium roof. No propping could be allowed under it due to the need to allow operations to commence. Where construction loadings were excessive, alternative staged construction techniques or suspended systems were necessary. For example, the 2 m and 3 m thick transfer plates were cast on steel falsework systems supported only at the column locations.

Design and construction of trackwork

Design

50. The seven-day service, with only restricted overnight periods for maintenance, influenced the choice of a concrete trackbed. Continuous rail support was chosen to improve ride and noise characteristics and it also enabled the BS 90A rail

Fig. 18. Kowloon Bay Depot: falsework for podium roof

section, with its economical proportion of head area to total area, to be used. The Pandrol fastening was specified because of its low cost combined with proven maintenance-free properties. The combination of all these features minimized maintenance time and cost. Alignment standards and track-laying tolerances are set out in Tables 3 and 4.

51. It was decided that the continuous support to the rail would be provided by two rail plinths rather than a more conventional track slab except in the areas of points and crossings. This required the minimum amount of concrete to be placed by the permanent way contractor, as the base slab concrete was provided under the main civil engineering and tunnelling contracts. In certain areas sensitive to noise and vibration, the rail plinths are mounted on a floating concrete slab (Figs 19 and 20). Ballasted track with precast concrete sleepers, except for points and crossings, was chosen for the depot stabling and fans.

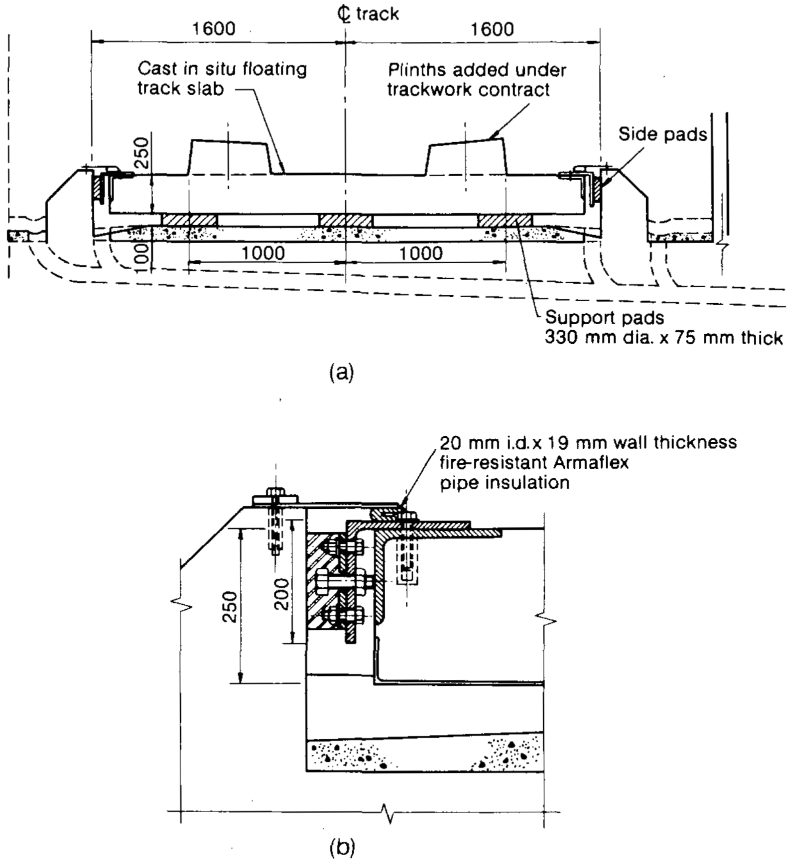


Fig. 19. Floating track slab (dimensions in millimetres): (a) section through slab; (b) detail of edge seal and side pad fixing

52. On the elevated line structures, a more substantial form of track plinth was necessary to ensure that a derailed train would remain on the structure. The track and plinth arrangement for tunnels and the elevated structures is shown in Figs 21–23.

53. The track plinths and slabs were designed in accordance with the relevant requirements of CP 110. In order to minimize stray leakage currents in the main structure, the longitudinal reinforcing bars were isolated from the trackbed starter bars by use of plastic clips. The longitudinal bars were discontinuous at track circuit joints to avoid attenuation or other interference with the signalling system. In each track circuit section they were connected externally to the traction fault current return wire to provide a low resistance route for the leakage currents to return to the negative earth bar of the traction substation.

54. Expansion joints were installed at all structural movement joints in the overhead viaduct structure (Figs 24 and 25). A shear device prevents relative lateral movement of the structure at the movement joints (Fig. 26). Conventional points and crossings, using vertical rails, were specified throughout. The principal dimensions are shown in Table 5 and Fig. 27.

Track plinth construction

55. The contract for the track-laying and construction of track plinths, for approximately 15·5 km of double track, was awarded to a joint venture of Henry Boot Construction Ltd and Gammon (Hong Kong) Ltd.

56. The contractor devised a simple system for constructing the plinths based

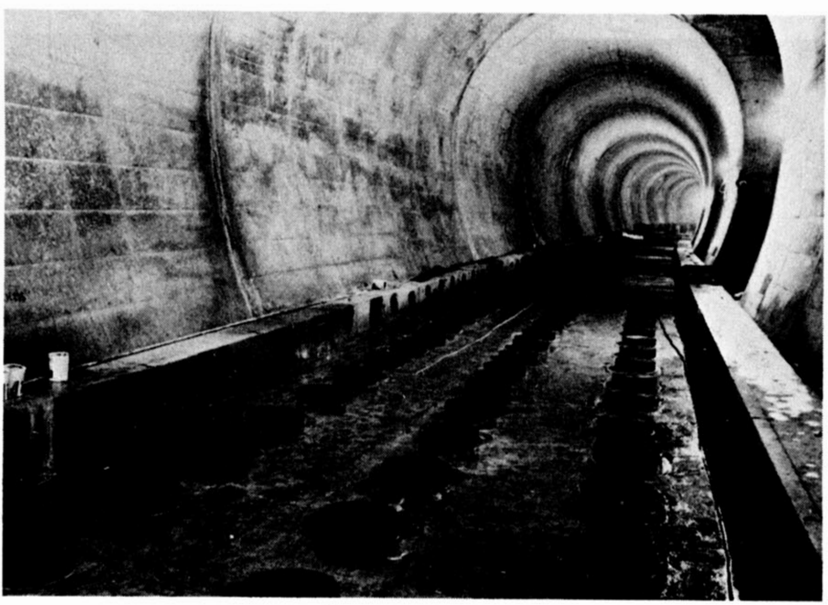


Fig. 20. Floating track: resilient support pads

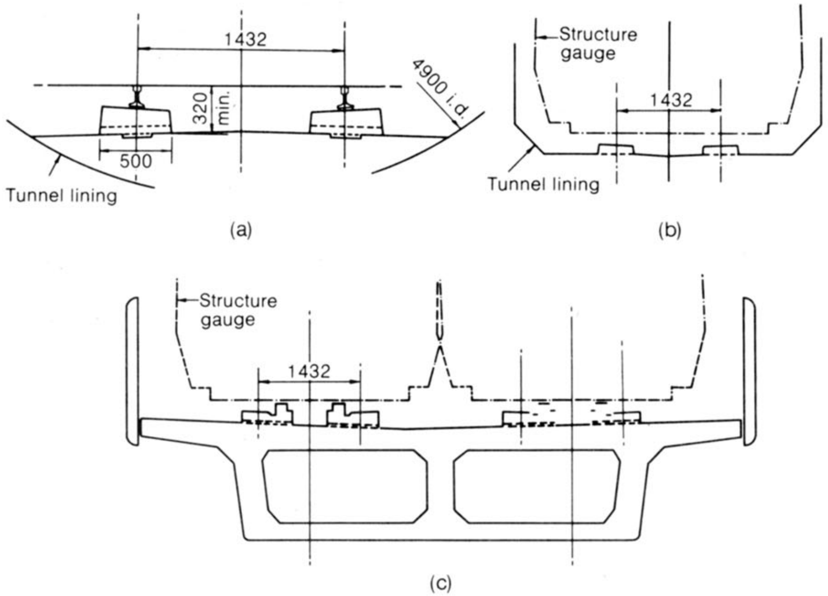


Fig. 21. Typical straight track sections (dimensions in millimetres): (a) circular and horseshoe tunnels; (b) cut-and-cover tunnels; (c) double tracks, overhead structure

Fig. 22. Track with derailment upstands

on the use of steel shutters and precise casting of the Pandrol shoulders in the plinths (Fig. 28). Each 3 m long section of prefabricated steel shutter consists of four upright steel panels. These panels form the 1 in 12 flared sides of the plinths, and the panels are fixed at that precise angle to two top transverse steel girders. The prefabricated section is machined accurately so that the geometric configuration of each section is uniform.

57. Two pairs of Pandrol shoulders are held in position by simple pins on a 'Pandrol support bar'. The Pandrol support bars, at either 600 mm or 750 mm centres depending on the curvature of the track, are clipped to the top of the steel shutter assembly.

58. As the shutters are in short sections, they are inexpensive to fabricate, and the system has three major advantages: normal railway curves can be accommodated, the forms can be transported down small shafts and accesses, and the system is flexible in that it can be assembled in short lengths or long lengths as desired.

Fig. 23. Rail plinth starter bars

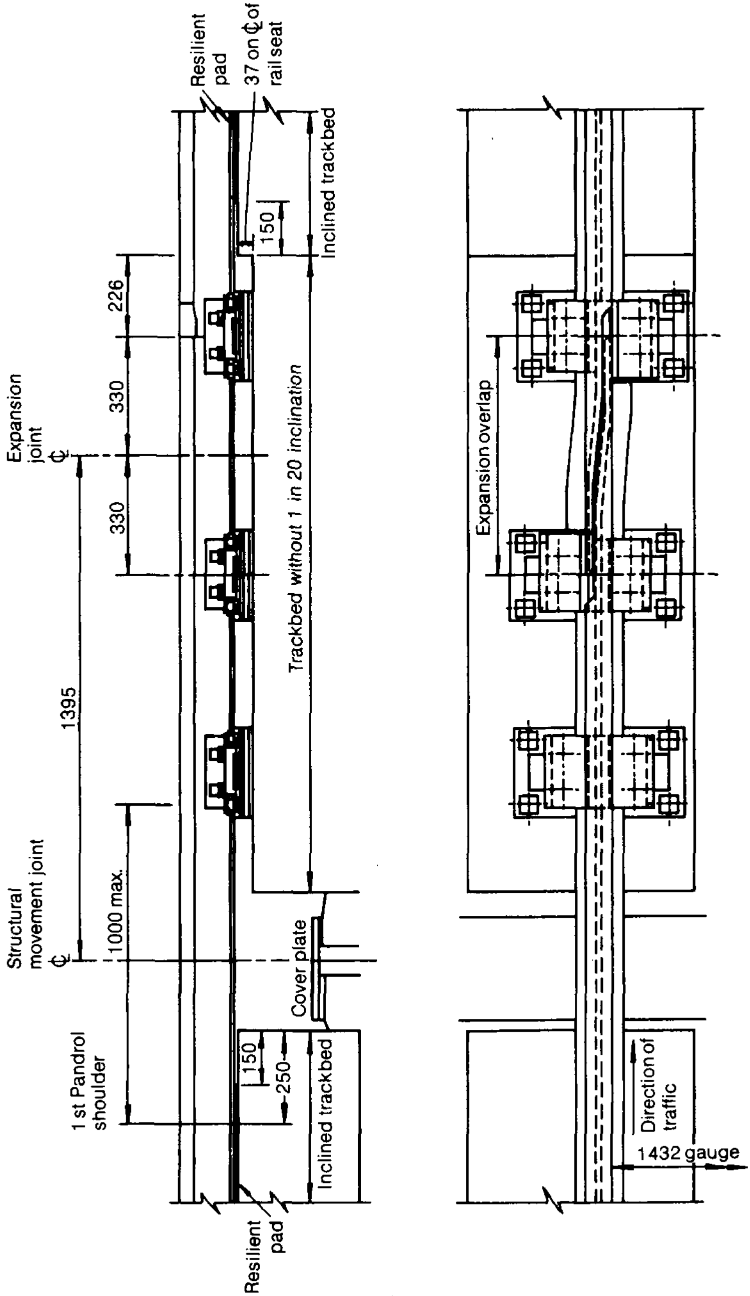


Fig. 24. Rail expansion joint (dimensions in millimetres)

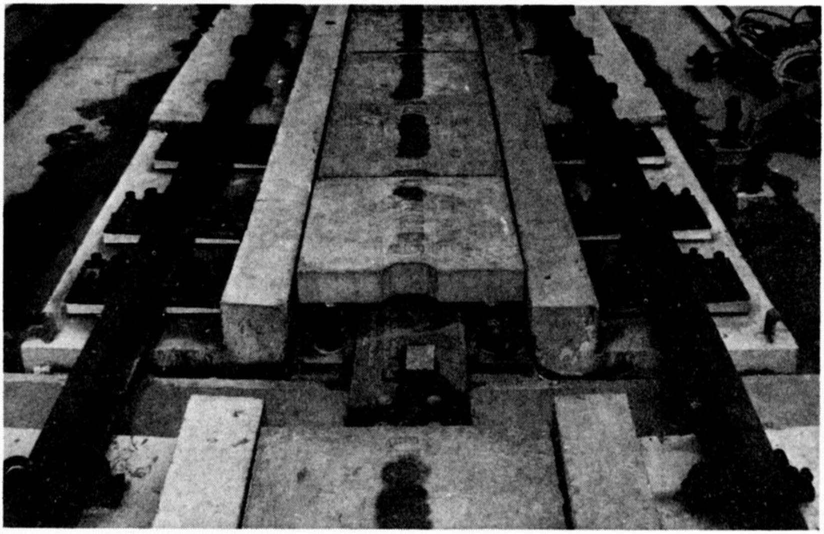


Fig. 25. Rail expansion joint and shear device

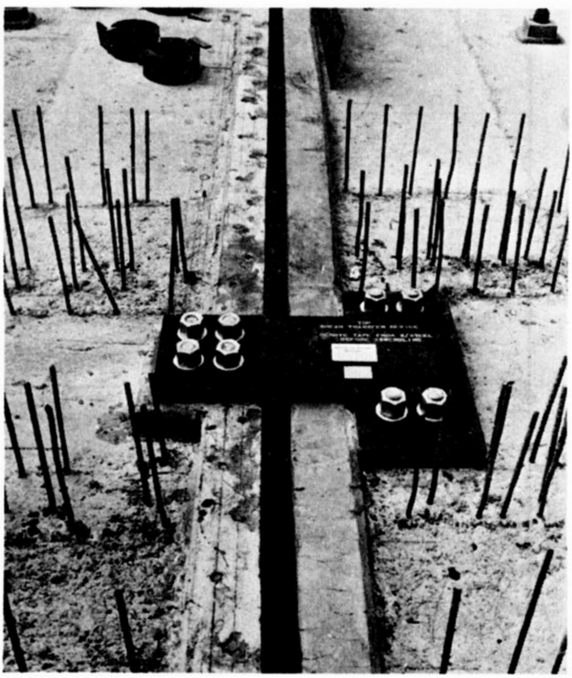


Fig. 26. Shear device

Table 5. Variable dimensions (metres)

Description		1 in 7 on timber	1 in $10\frac{1}{2}$	1 in 14	1 in 18
Radius of switch and turnout curve	R_1	141·052	316·472	562·060	928·652
Radius of centre-line of switch and turnout curve	R_2	140·336	315·756	561·344	927·936
Length of stock rail		9·770*	14·850	17·715	17·715
Length of switch rail		8·890*	13·860	17·485	17·485
Stock rail joint to toe of switch	T	1·540†	1·650	1·650	1·650
Origin of radius of turnout to toe of switch	S	1·437	1·296	1·657	2·578
Switch entry angle		0°–52′–23·87″	0°–17′–35·59″	0°–12′–32·22″	0°–12′–25·26″
Crossing angle		8°–10′–16·6″	5°–27′–9·4″	4°–5′–26·9″	3°–10′–56·2″
Intersection of gauge lines to crossing nose (0·016N)	F	0·112	0·168	0·224	0·288
Crossing nose to heel of crossing	P	5·445†	4·690	5·400	5·400
Wing rail joint to crossing nose		3·070	3·070	3·780	3·780
Lead length (toe to intersection of gauge lines)	L_1	18·611	28·776	38·439	48·974
Lead length (toe to crossing nose)	L	18·723	28·944	38·663	49·262
Stock rail joint to delta point	A	10·127†	15·390	20·041	24·848
Delta point to crossing heel joint	B	15·581†	19·894	25·672	31·464
Stock rail joint to crossing heel joint	C	25·708†	38·284	45·713	56·312
Delta point to intersection of gauge lines	GN	10·024	15·036	20·048	25·776
Turnout speed, km/h		30	45	65	80

* Dimension subject to amendment to suit the requirements of a 1 in 7 turnout in continuously welded track.
† Dimension subject to amendment to suit the requirements of a 1 in 7 turnout on concrete.

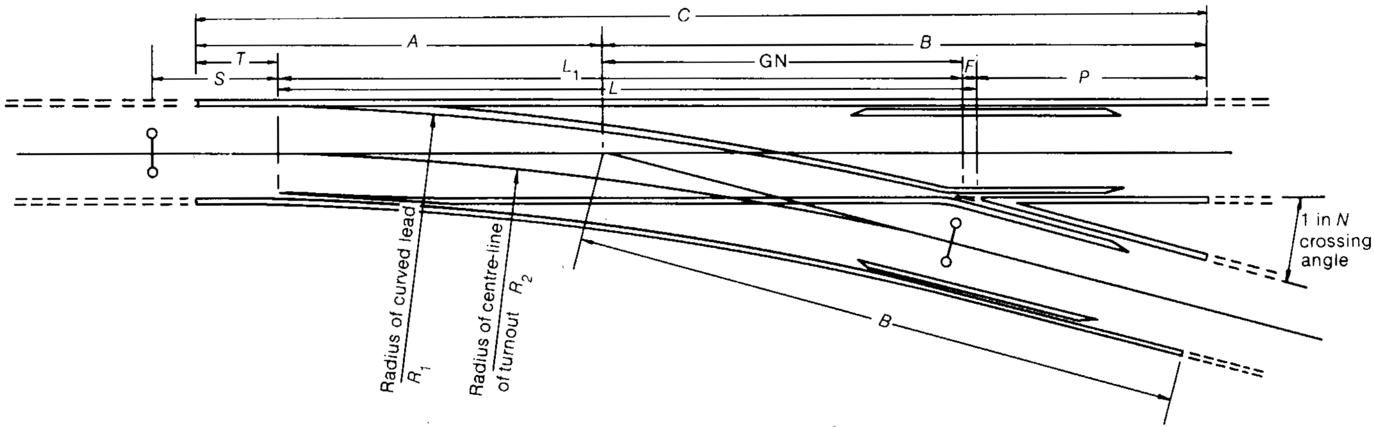


Fig. 27. Points and crossings: layout and principal dimensions

59. The design of the forms is based on the positioning of the Pandrol support bars which are the key to the system and give the track precise gauge, line, level and superelevation. Fixing in the field was thus rationalized to the setting out of three items:

(*a*) one locating pointer governing the positions of the four panels relative to each other;
(*b*) the heights of the panels from the base concrete;
(*c*) the levels and offsets of the Pandrol support bars.

The calculation of setting-out measurements from data specified in the form of coordinates, levels and offsets relative to monuments established at generally 10 m centres is complicated and was therefore carried out by computer.

60. An average production rate of 51 m of twin rail plinth per day per workforce, using a single gang of 30 men and one set of prefabricated forms on a daily

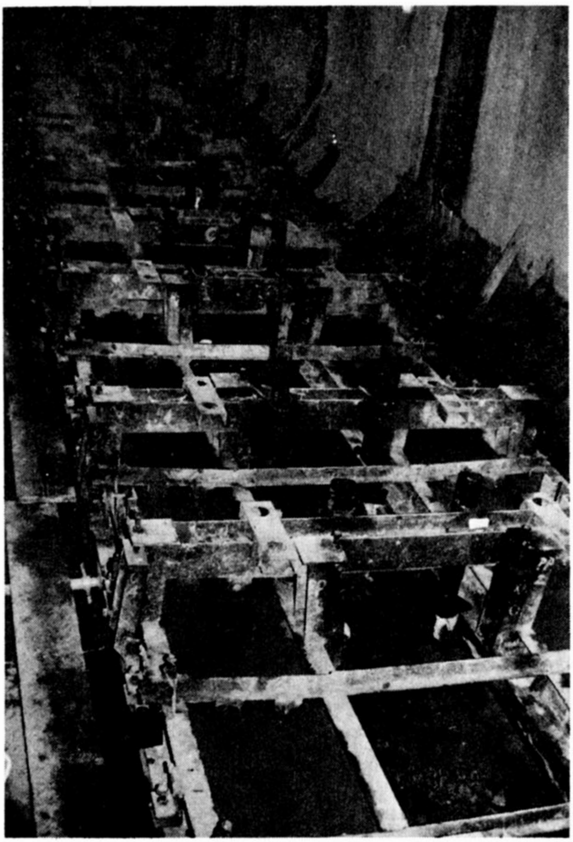


Fig. 28. Plinth formwork, concreting completed

turnaround basis, was achieved. Generally four faces were worked concurrently. Experience proved the system to be highly flexible in coping with the programme delays which were to be expected on a multi-contract project of this nature. Several accelerations to the trackbed programme were made to accommodate late and phased access and yet the original opening dates were improved upon.

61. Concrete was delivered by means of a monorail system with the tray arranged to tip to either side into the two plinths. Compaction was by conventional vibration, and the surface was trowelled by a guide screed registering to the Pandrol bars. Latterly, in the interests of flexibility, the monorail was discontinued and modified dumpers were used. Most of the track plinth was cast to the specified standard of accuracy, with only a small percentage requiring simple remedial works (Fig. 29).

Tracklaying

62. For the long welded rail on plain track, a welding plant was established at the permanent way depot at Kowloon Bay where standard lengths of 18 m were welded into 90 m lengths using the Thermit SKV process. These rails were transported on trains equipped with deck-level rollers and hydraulic jacks.

63. Two battery-powered locomotives were used and were equipped to pass the rails over the locomotive shoulders on to roller guides attached to the Pandrol shoulders on the plinths. The rails were jacked down on to the resilient pad which had been glued on to the plinth, the Pandrol spring clips were inserted and the thermit welding was completed. This system was self-contained, with power requirements provided from the locomotives. Six long welded rails per day were completed.

Fig. 29. Track plinth completed

Fig. 30. Kwun Tong scissors crossover

64. For points and crossings, which were on flat slabs rather than plinths, the Pandrol clips were glued into diamond-cored holes. Eleven scissors crossovers and 18 plain turnouts were constructed in this manner (Fig. 30). Conventional methods were used for laying the 17 km of ballasted track in the depot.