KCRC EAST RAIL EXTENSIONS SPECIAL ISSUE 3/2007

The Arup Journal

Contents

On 2 December 2007, after three years of negotiation, the MTR Corporation Ltd (MTRCL) and the Kowloon-Canton Railway Corporation (KCRC) were merged. All Hong Kong's trains are now operated by the MTRCL. As a result of the merger a small number of station and line names changed. This edition of *The Arup Journal* was completed before the merger.

Foreword

After 10 years' planning, design, and construction, the opening of the Lok Ma Chau spur line on 15 August 2007 marked the completion of the former Kowloon-Canton Railway Corporation's East Rail extension projects. These complex pieces of infrastructure include 11km of mostly elevated railway and a 6ha maintenance and repair depot for the Ma On Shan line, 7.4km of elevated and tunnelled route for the Lok Ma Chau spur line, and a 1km underground extension of the existing line from Hung Hom to East Tsim Sha Tsui. Arup was involved in all of these, from specialist fire safety strategy for all the Ma On Shan line stations, to multidisciplinary planning, design, and construction supervision, and, on the Lok Ma Chau spur line, direct work for a design/build contractor.

In some cases our involvement went from concept through to handover. For example, we were part of a special contractor-led team that carried out a tunnel feasibility study for the Lok Ma Chau spur line across the ecologically sensitive Long Valley.

At East Tsim Sha Tsui station we worked closely with the KCRC and numerous government departments to re-provide two public recreation spaces - Middle Road Children's playground at the foot of the historic Signal Hill, and Wing On Plaza garden - examples that show the importance of environmental issues for the KCRC in expanding Hong Kong's railway network.

This special issue of *The Arup Journal* is devoted to all of our work on the East Rail extensions, and our feasibility study for the Kowloon Southern Link, programmed to connect West Rail and East Rail by 2009. It also outlines some of our railway-related property work with the KCRC's property development teams. This notable body of projects adds significantly to Hong Kong's efficient railway network.

I would like to take the opportunity to thank all firms, organizations, and statutory bodies involved, as well as our own staff, past and present, for bringing them to a successful conclusion.

Timothy Suen
Director, Railway Group, Hong Kong

The Tsim Sha Tsui extension:
an introduction

Colin Wade

This forms a 1km extension of the existing East Rail service which, until the opening of the new East Tsim Sha Tsui station, terminated at Hung Hom station. Hung Hom itself continues to be the terminus for the through train service to Guangzhou (formerly Canton), Shanghai, and Beijing.

This new extension brings the railway back into the tip of the Kowloon Peninsula some 29 years after the original 1914 terminus closed following the opening of Hung Hom station in 1975. Initially functioning as a terminus, the new station allows passengers to interchange via an air-conditioned pedestrian subway with the MTRC's existing Tsim Sha Tsui station on the Tsuen Wan Line beneath the nearby Nathan Road. On completion of the KCRC's extension of West Rail south of Nam Cheong station, now under construction (The Kowloon Southern Link), East Tsim Sha station will revert to being a through station.

The extension was split into two detailed design packages, of which Arup's share was some 90%; the second package covered modifications and some new works both inside and outside Hung Hom station. Five construction contracts were let (HCC) - four of them under Arup's remit. The fifth was the Hung Hom station works.

Arup's consultancy agreement HDD300 covered East Tsim Sha Tsui station itself (contract HCC300), the running tunnel between it and the existing station at Hung Hom (HCC301), the pedestrian subway network between East Tsim Sha Tsui and the MTR Tsuen Wan Line station (HCC302), and a cable tunnel beneath the KCRC's freightyard at Hung Hom for the China Light & Power Company.

These three contracts represented some 96% of the Tsim Sha Tsui extension project costs and are described separately in the following articles.

1. Comparison of original and new railway routes.

2. The Tsim Sha Tsui terminus in 1914. Signal Hill and its Tower, which have survived all the new works, can be seen top left.

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1. The station from Salisbury Road.

East Tsim Sha Tsui station:
engineering planning, design, and construction

Timothy Suen Colin Wade

History

The original terminus at Tsim Sha Tsui waterfront

Kowloon's Tsim Sha Tsui terminus was the subject of much debate during implementation of the original Kowloon-Canton railway, officially opened on 1 October 1910 by His Excellency the Officer Administering the Government, Sir Henry May (in the absence of the Governor, Sir Frederick Lugard).

Originally the terminus was a temporary rented building owned by the Hong Kong & Kowloon Wharf and Godown Company, near the present-day Star Ferry Pier on the tip of the Kowloon peninsula, but eventually the colonial government decided to build a permanent terminus on a tract of reclaimed land now occupied by the cultural complex. This avoided the cost of land resumption and was ideally placed for ocean-going steamships berthing nearby, greatly simplifying the transfer of goods between ship and rail.

The new permanent terminus was a handsome two-storey brick/granite structure, with elegant classical columns, pediments, architraves and balustrades, an accompanying lofty clocktower, and a colonnade stretching along the harbour's edge to the Star Ferry Pier. The spacious concourse led to two island platforms, 183m and 213m long. The foundations were completed by the end of 1913 and the platforms opened in 1914, although the station was not fully commissioned until early 1916, and the clocktower only completed in 1921. From the terminus the railway ran east, past the site of what is now the Peninsular Hotel, turned north alongside Chatham Road, and into the hinterland beyond Ho Man Tin district.

The move to Hung Hom

On 29 November 1975 the terminus closed to the sounds of "Auld Lang Syne" as the last scheduled train arrived. Demolition began soon after, including removal of the tracks alongside Chatham Road all the way to Ho Man Tin where they formed a spur off the realigned main line to form a livestock handling siding. Only the clocktower was left standing to commemorate the old station.

2. (above) and 3. (below) Tsim Sha Tsui in 1971 and 2003, showing (a) Star House, (b) Hong Kong Hotel, (c) YMCA, (d) Peninsula Hotel, (e) Middle Road multi-storey car park, (f) Mariners' Club, (g) Signal Hill (formerly Blackhead Point), (h) Holts Wharf (now occupied by New World Centre - see below), (i) Wing On Plaza, (j) Wing On Plaza garden, (k) Signal Hill Tower, (l) New World Centre, (m) Middle Road children's playground (the station site), (n) Sheraton Hotel, (o) Hermes House, (p) Salisbury Road underpass under construction.

Passenger services recommenced on 30 November 1975 from the new terminus station known as "Kowloon", renamed "Hung Hom" in 1998 after the opening of the MTRC's Kowloon station[1] for the Lantau & Airport Railway. Hung Hom served as the terminus for the domestic urban service and still forms the terminus for the through-train service to Guangzhou, Shanghai, and Beijing.

Development of the station planning

Previous studies

In 1997 the KCRC Board endorsed the principle of studies undertaken for the Government on extending East Rail to connect with West Rail. Originally the West Rail line was to extend to West Kowloon but it was later decided to terminate it initially in the Sham Shui Po district at Nam Cheong station. A feasibility study by other consultants for the KCRC included examining the available corridors between Hung Hom and the potential West Kowloon station.

The chosen corridor (Fig 4) for the extension ran beneath Salisbury Road, Wing On Plaza garden, Signal Hill and, using a late 1970s MTR reserve for the as-yet-unbuilt East Kowloon Line, passed under Middle Road to initially terminate at Kowloon Park Drive. This gave sufficient length for a turnback track arrangement to allow East Tsim Sha Tsui to initially operate as a terminus for East Rail. Future extension of this alignment would then have entailed passing beneath the former Marine Police HQ site east of Canton Road, beneath Ocean Centre, and on to West Kowloon. This was originally based on the premise that Kowloon Point reclamation would proceed. However, to not frustrate railway construction, the assumption was made that beyond Ocean Centre the railway would be built in an immersed tube to connect with West Kowloon station. The alignment required underpinning of Ocean Centre – technically feasible but clearly undesirable.

The KCRC's East Tsim Sha Tsui study also assumed that the existing Mariners' Club building at the east end of Middle Road (which was encroached on by the station box) would be redeveloped and could be included in the station planning as the owners were considering redevelopment. This would allow the station length to accommodate the current 290m 12-car East Rail trains until the nine-car West Rail trains connect with East Rail and allow 12-car trains to terminate at Hung Hom.

In September 1998 the Government invited the KCRC to proceed with the Tsim Sha Tsui extension, but by spring 1999 the KCRC was less confident that the Mariners' Club site would be redeveloped and consequently reduced the station length to accommodate only the 217m nine-car trains and avoid encroaching on the club site. Further changes were made, including deletion of the long overrun tunnels along Middle Road and instead providing a small length of overrun west of the now shortened station. The detail design of the Tsim Sha Tsui extension was then competitively tendered to consultants in April 1999 using the nine-car station as the conforming proposal.

4. KCRC extension, Hung Hom to West Kowloon (1997/98).

5. Signal Hill Tower.

Scheme development

Arup was appointed in July 1999 as consultant for the KCRC's design contract HDD300. From the outset, the design team spent considerable effort in reviewing alternative railway alignments and station configurations to those put forward by the KCRC. Because of the alignment beneath the constrained width of Middle Road, the KCRC conforming proposal led to a side platform arrangement on a curve, with a 0.5% vertical gradient over the platform length and the nine-car length constraint noted previously. For passengers to exit the last three cars of a 12-car train beyond the platform end, train ambassadors would have to direct them along the train prior to its arrival. This was, to say the least, unsatisfactory both operationally and for users, even though it would be for a limited time – some five or six years in theory – until the nine-car West Rail line connects to East Tsim Sha Tsui station. The challenge was provide a station long enough for 12-car trains with if possible a level and straight island platform - clearly a superior solution.

Concurrently with contract HDD300 Arup was also engineering consultant for a separate KCRC property development study at the station, planned to provide a tall commercial tower on the Middle Road children's playground site.

This scale of development also severely constrained the KCRC Middle Road alignment, and the KCRC's conforming proposal gave the team two other major concerns, namely:

(1) the need to demolish part of the existing Mariners' Club building due to encroachment of the station box if a 12-car platform was reintroduced

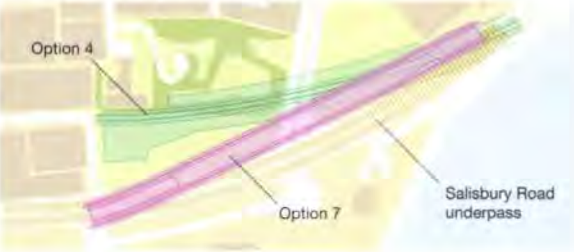
(2) the need to remove the southern part of Signal Hill, including some 100 trees, a 16m tall masonry retaining wall, and the 15m high soil slope above it.

For (1), due to the potential difficulties with resuming the Mariners' Club site, an alignment not encroaching into its site boundary was desirable, but (2) gave greater challenges as the hill has great historical value for Hong Kong. Formerly named Tai Pau Mai (Blackhead Point) and originally on the tip of Kowloon Peninsula, it houses a small garden and recreation area and, most significantly, the Signal Hill Tower (Fig 5), built in 1907 to house a time-ball apparatus. Precisely at 1pm daily, a large hollow copper ball dropped by a special mechanism from the top of the tower to its foot served, long before radio broadcasting, as a time signal visible to ships in the harbour for checking the accuracy of navigation chronometers. The practice was judged obsolete by 1933 and discontinued, but the tower was restored in 1980 and has since been maintained by the Urban Council.

The KCRC's conforming proposal required part of the hill's south face to be severely cut back, with extensive retaining structures supporting what remained. Station accommodation within a concrete superstructure was to be built in its place, and the hill "re-formed" with a series of terraces, staircases, ramps, etc. Whilst the proposal would not touch the tower itself, it would be very close to the crest of the cut back hill and hence potentially vulnerable to movement during removal of the hill face. The design team regarded touching the hill as highly undesirable from both the geotechnical and heritage viewpoints, as well as on cost and programme grounds. The scheme was also objected to by some environmentalists.

The team and the KCRC held a series of value engineering workshops to review station and alignment ideas. Six proposals were initially sketched, ranging from keeping the conforming proposal but using bored tunnel techniques for the station platforms, to cut-and-cover ideas on various alignments. However, the challenge of finding a solution involving neither the Mariners' Club nor Signal Hill constraints remained. Further workshops and design sessions questioned why the Middle Road alignment at all? During Phase 2 of the Government's first railway development study (RDS), an alignment had been proposed along Salisbury Road, west of its junction with Chatham Road South, with a station near the Peninsula Hotel and Cultural Centre area (Fig 7). This route, however, still presumed that the Kowloon Point reclamation would proceed; its alignment passed between the Star Ferry bus terminus and Star House, and continued beneath Ocean Terminal to clash with other jetties north of it. After further team brainstorming and value engineering workshops, the initial six options and an additional one for Salisbury Road were systematically scored and judged by the team and the KCRC. Two contenders were identified, options 4 and 7 (Fig 6).

6. Option 4 & 7 comparison.



7. RDS Phase 2, showing Middle Road and Salisbury Road corridors.

8. Option 7 corridor compared to RDS Phase 2.

Option 4 was similar to the KCRC's conforming proposal, accommodating nine cars on a 1000m horizontally curved side platform station and a flat vertical alignment along the platform, while option 7 provided a 12-car straight island platform on a flat vertical alignment under Salisbury Road. However, Arup's option 7 proposal differed fundamentally from the RDS. Instead of the future extension beyond East Tsim Sha Tsui station passing onto a (very uncertain) Kowloon Point reclamation, it curved under the junction of Salisbury Road and Kowloon Park Drive into an alignment beneath the former Marine Police HQ site, below Canton Road and thence north to connect with a relocated West Kowloon station (Fig 8).

This alignment became known as the Kowloon Southern Loop, since renamed the Kowloon Southern Link (KSL), and was seen by the KCRC as significant in several ways:

- East Tsim Sha Tsui station itself could cope with 12-car trains on a straight island platform and hence was operationally superior.
- The KSL alignment south of West Kowloon station did not depend on reclamation at Kowloon Point.
- The KSL south of West Kowloon station did not need to be built as an immersed tube nor include costly provision for a possible Kowloon Point station.
- An alignment under Canton Road gave potential for a very conveniently located new station, possibly in the road itself, enhancing service to the travelling public.
- No costly underpinning was needed for Ocean Centre, Ocean Terminal, or other nearby jetties.

Option 7 alignment: the challenges

While this alignment was an exciting concept both to the team and the KCRC, it had its own constraints (Fig 9):

- Part of the station box was beneath a listed "Champion Tree" (no 251) at the corner of Salisbury Road and Middle Road.
- The station box was immediately adjacent to and partly clashing with the proposed Salisbury Road underpass, a Highways Department project designed to ease the at-grade junction of Chatham Road South and Salisbury Road.
- The station overrun tunnel passed beneath a newly-built 24-hour public subway under Salisbury Road between Middle Road and the New World Centre south of Salisbury Road.

Following further sketch development of alignments, station construction methods, and ways of dealing with these constraints, option 7, and its extension into the Canton Road corridor, was presented to the KCRC senior management.

A pre-feasibility study to confirm that a Canton Road alignment was technically viable was tackled fast-track by a special Arup task force in late 1999, and following further presentations to the KCRC senior management, option 7 and this alignment were accepted in early 2000. The KCRC also decided not to proceed with its planned property development on the station site. The team then focused on producing a detailed design package for the entire HDD300 project for tendering and procurement, with a contract award by April 2001 and practical completion by late summer 2004.

9. Option 7 constraints at time of scheme development.

Fire engineering

All railway station designs and associated facilities (depots, ancillary buildings, etc) are rigorously vetted by Hong Kong's Safety and Security Coordination Committee (SSCC), chaired by the Chief Inspecting Officer of the Hong Kong Railways Inspectorate. The SSCC includes representatives of Government departments concerned with public safety, as well as the railway operator. The KCRC submitted the East Tsim Sha Tsui station design to the SSCC for formal endorsement, based on its previous fire strategy used on the West Rail projects some years earlier. Arup was called on to justify all these previously adopted parameters and to present the findings to the Fire Safety Committee of the Government's Buildings Department for endorsement, before gaining final SSCC approval.

The KCRC was highly satisfied with Arup's comprehensive fire safety strategy for the station and as a result commissioned the firm to provide justification of the fire safety strategy for the entire Ma On Shan Rail line to optimize the design in a cost-effective manner. This work is described on pp40-42.

10. The KCRC model for public display showing: (a) Champion Tree, (b) Middle Road childrens playground, (c) Mariners' Club, (d) Signal Hill Tower, (e) Signal Hill garden, (f) Chatham Road South, (g) Wing On Plaza garden, (h) Wing On Plaza garden station plantrooms, (i) Salisbury Road, (j) Concourse level, (k) Platform level, (l) Station electrical substation, (m) Ground level public trading, public light bus terminus, drop-off, etc, (n) Wing On Plaza.

Design: general description of the station and associated structures

Components

The KCRC had a model built for public display in its community information office near the site during construction (Fig 10). Initially the project's principal elements (see also Fig 11) were planned as:

Platform/track level: 512m long railway box comprising 103m long plantroom and overrun tunnel section; 291m long straight platform; and 118m long plantroom and eastern approach tunnel section (constructed under the station contract)

Concourse level: above and beyond the platform zone as an irregular plan shape beneath Middle Road children's playground, Wing On Plaza garden and Chatham Road South; accommodates paid and unpaid concourse areas, back of house areas, station and tunnel ventilation plantrooms, station trading, subway connections, and entrances

Ground level/Middle Road children's playground: main station entrance, with adjoining franchised and public light bus terminus, taxi and car drop-off and pick-up zone, plus service yard area for station and the landscaped deck, transformer rooms, landscape deck access, station trading areas, and ventilation structures

Ground level/Wing On Plaza garden: station entrance, transformer and plantrooms, ventilation structures, and re-provisioning of the original garden and its former amenities

Deck level: landscaped garden with service rooms, toilets, kiosks and play areas

East Tsim Sha Tsui promenade: underground seawater intake and pump chamber structure for station cooling, just behind the harbour seawall.

Ground conditions and geology

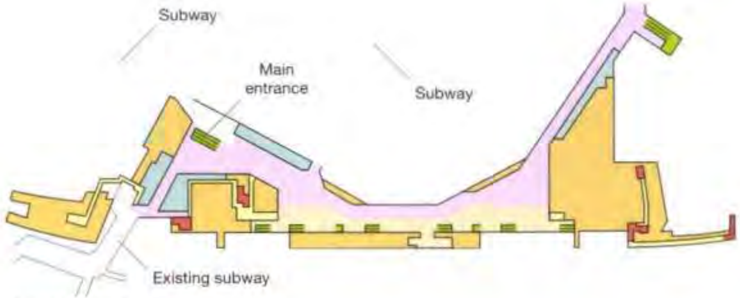
The west part of the station box is at the foot of Signal Hill, slightly inland from Kowloon peninsula's original shoreline. Land was reclaimed here for the original KCRC railway between 1913 and 1914, and by 1924 the shoreline was roughly on the seaward edge of the existing New World complex. Bedrock contours over the station site are quite variable: the zone against Signal Hill is the highest, with competent rock only some 2m below ground, whilst at the approach tunnel zone near Wing On Plaza it is some 40m below ground. At this easterly zone, bedrock is overlain by layers of completely and highly decomposed granite (CDG and HDG), alluvium, some marine deposits, and fill material, all of varying thicknesses. In the children's playground area the geology is predominantly CDG overlain by fill. Because of the high rockhead, much rock excavation was needed to form a trackway some 19m below street level and the offset concourse formation level some 10m down.

11. The project's principal elements.

a) Section through the west end, beneath the Middle Road children's playground.

b) Section through the east end, beneath Wing On Plaza garden.

c) Plan at ground level.



d) Plan at concourse level.

e) Plan at platform level.

Perimeter retaining wall construction

Several schemes were reviewed in conjunction with the likely excavation methods, given the high rockhead and constraints around the site. Diaphragm walling was ruled out early on, a traditional cast in situ system being identified as the most cost-effective. Contractors, it was assumed, would opt for a temporary cofferdam using a mixture of strutted sheet piles or pipe piles toed into rock, plus anchored rock faces where rockhead is high, and the main contractor duly adopted this method (Fig 12). At Wing On Plaza garden the sheet pile cofferdam was stabilized by H-piles anchored back via waling beams using a stressed anchor system that enabled the strands to be destressed and retrieved as permanent structural slabs were completed. Strand retrieval is mandatory under the local regulations wherever anchors extend beyond a site boundary. The contractor opted to use the Japanese *Koken* system - believed to be its first use in Hong Kong (Fig 13).

Foundations/uplift

Early in the design, the team adopted solutions judged appropriate to the rockhead conditions, site constraints, and uplift loadcases. Large piling rigs excavating through rock were not seen as cost-effective, nor in some cases would they be easy to locate on site due to the temporary traffic management requirements in this busy neighbourhood.

The railway alignment and hence station depth were dictated by a number of constraints:

- Both the overrun tunnel structure and the future extension beyond it for the KSL had to pass below two newly-completed pedestrian subways beneath Salisbury Road.
- The future KSL needed to clear the existing MTR Tsuen Wan Line running tunnels under Nathan Road.
- The Salisbury Road underpass structure partly oversails the station box.
- Utilities east of the station in Salisbury Road severely constrain running tunnels.

These factors led to a rail level 17.5m below street within the station, and the station box roof level about 4m below ground. In several places this led to a deep soil cover over the station which has assisted uplift resistance. A mix of foundations was identified at tender as the most cost-effective:

- strip and isolated pad foundations founded on rock, supplemented by pre-bored H-piles socketed into rock to resist uplift where necessary
- bored piles where rockhead was much deeper than formation level and where pad footings were not practical
- pre-bored H-piles beneath the east approach tunnel box, socketted into rock
- strip footings in the overrun tunnel box founded on rock, supplemented by pre-bored H-piles socketted into rock to resist uplift.

Foundation construction generally followed the tender drawings with no significant changes. For programme and access reasons, some areas of the approach tunnel foundations were varied from bored piles to H-piles and from bored piles to ground bearing. In the overrun tunnel section, some H-piles were changed to mini-piles specially detailed to be installed after completion of the track slab structure.

Station box structure

The station comprises an in situ reinforced concrete box constructed within the temporary cofferdam.

The column arrangement for the platform was decided at an early stage. Longitudinally, the 24.136m KCRC train car module was used as the basis for the architectural grid, leading to a 12.068m spacing. Laterally, either no columns or a single column led to difficulties with the large spans across the width of the trackway box, particularly at roof level where soil depth made for large column loads. In addition, framing around escalator and stair voids became problematic, so a twin-column system was adopted, leading to tolerable lateral spans of 9m, 7.45m, and 9m across the platform box between perimeter retaining walls (Fig 20).

12. Temporary strutted and anchored perimeter retaining wall construction.

13. Stressed anchor system at Wing On Plaza garden excavation.

14. Positioning overtrack exhaust duct units.

Although the station shape at concourse level is very irregular, a 12.068m by 12m grid was adopted as the base module for the entire box beyond the trackway zone.

Early in the design, the team made cost comparisons between flat slab, one-way beam-and-slab, and two-way wide beam-and-slab configurations for the suspended floors and roofs. The latter was chosen as the cheapest option and generally adopted for all the suspended levels, albeit with some variations due to the numerous constraints from the architectural planning and E/M services.

The need for a particular column arrangement to suit the taxi-drop off zone, as well as the very heavy landscaped deck above it, gave rise to several transfer beams being incorporated at concourse roof level due to the different column layout in the concourse below.

Precast elements

Part way through construction, the Arup and KCRC project management teams decided that the contractor should investigate potential programme savings to ensure timely completion. Civil works appeared to benefit from this rather than later follow-on finishes and building services elements, and brainstorming sessions tackled possible areas. However, due to the largely irregular shape of the station box, particularly above platform level, no practical means of achieving this for the main structural elements could be found at the time. Instead, it was felt that some secondary structural elements should be investigated and here time savings were developed in two areas, the overtrack exhaust duct system and the public platform. These were indicated and detailed at tender stage as in situ concrete and, although fully co-ordinated drawings had been produced, a contractor/designer task force immediately began to study the use of precast elements for them.

Overtrack exhaust ducts

Both KCR and MTR services operate with fully air-conditioned train cars, cool air being provided by roof-mounted condenser units that expel hot air. In stations these units line up with horizontal openings in overtrack ducts that run parallel to the trackway and feed back into the ends of platform ventilation fan rooms. Another function of the overtrack ducts is to also remove smoke should a fire occur on the trackway.

The overtrack exhaust ducts were redesigned as a series of U-shaped units hanging from the concourse slab, and design sessions were held with the contractor's site staff and the precast manufacturer to arrive at the optimum details to suit production, demoulding, handling, transportation, erection, and positioning. As concourse construction was under way using the tendered beam-and-slab structure, these units had to fit around the beam shapes. This required variations in the unit shape, but no insurmountable difficulties were met. Each unit is suspended by four high yield threaded bars inserted into preformed sleeves through the concourse slab and through sleeves within the duct walls.

Site installation was simple and effective. The contractor devised and built a transportation gantry with a hydraulic ram system to lift and position units very accurately (Fig 14). The gantry was pulled along the trackway on rails and received units from ground level through an access opening in the station box via a secondary transporter rig.

Platform units

The platform was redesigned as a series of precast slab units carried by parallel precast wall units supported directly on the track slab without any in situ stitching. Instead, they are restrained laterally by in situ "kerbs" dowelled into the track slab.

Tops of walls are corbelled out to receive slab units with an adequate seating to simplify rebar junctions and out-of tolerance effects. The slab elements are broad units rather than narrow planks to avoid the use of an in situ concrete structural topping over the entire platform area, which would have partly defeated the object of precasting them. Instead, units were recessed on all sides to provide a localized in situ stitching strip. Short lengths of small diameter loose bars lap with bars projecting from the units to connect them. Bars projecting from the wall units provide connectivity between walls and slabs (Fig 15). Again, installation was simple and effective, using a small mobile crane to place wall and slab units (Fig 16) followed by pouring the in situ stitches.

15. Connection details between precast wall and platform units.

16. Installing a precast platform wall unit.

Benefits of precast solutions

A key date for all new railway projects involving trackwork is handing over of the trackway zone to follow-on systemwide contractors, particularly for track laying, so clearing the platform edge zone and trackway is a key driver in constructing civil works.

Avoiding in situ works here is beneficial, as precast construction does not involve waiting time to remove shuttering, formwork props, making good, etc. Environmentally, the precast solution also saved much timber formwork as the supplier used a minimal number of high-quality steel shutters blocked out as necessary for the inevitable specials and one-off units.

In programme terms, the in situ platform and overtrack exhaust works were originally scheduled to take almost six months to complete – the precast solution took a little over two months.

17. Champion Tree no 251 in its original location in the former Middle Road children's playground.

18. Champion Tree underpinning, with concourse construction under way beneath it.

Champion Tree no 251

Sited near the junction of Salisbury Road and Middle Road, Champion Tree no 251 is a significant example of *Ficus virens* – a large-leafed Banyan, one of only 10 of its kind in Hong Kong (Fig 17).

This tree is "listed" by the Government, and as such is protected from being cut down or tampered with, although as has been done before in Hong Kong, it could have been moved away from the site, either permanently or temporarily.

Due to the constraints of the Salisbury Road underpass, the track alignment could not be moved far enough away from the tree and hence part of the trackway and concourse had to be built beneath it. Schemes were reviewed to temporarily move the tree from the immediate area of the trackway to allow the platform and concourse level of the box to be built, but its survival was the issue and the temporary location would have still been within the works site, impeding progress, so this idea was not pursued.

A scheme to underpin the tree was then devised: a permanent horizontal pipe pile canopy beneath the roots supported by temporary crossbeams, in turn supported by a series of temporary steel king posts extending down to bear on the rock at final formation level of the trackway. A temporary in situ ring beam was to form a tree pot to encompass the roots and soil. This proposed construction was shown as part of the tender information for consideration by tenderers, and in principle was followed by the contractor (Fig 18). Significant involvement of the contractor, the KCRC team, and the Arup design and site staff teams, together with the Government's Leisure and Cultural Services Department, has been necessary to ensure the health of the tree at all stages of the station construction.

With construction complete, the tree is now in a new planter next to the perimeter wall of the ground level station facilities (Fig 19).

19. The tree in its final position above the station concourse, with the new Salisbury Road underpass just visible beyond the tree.

20. The station island platform, showing twin column arrangement flanking escalators.

Seawater intake and pump chamber

This structure is located on the site of a previous similar chamber built in the 1970s and used by the nearby Hong Kong Polytechnic University, which had decided to abandon its seawater cooling system and was prepared to hand the site over to the KCRC for re-use. Initial surveys indicated the structure as found would not provide the 120-year design life required by KCRC design criteria and was also unlikely to be large enough to house the new plant configuration. A new structure was therefore designed, a buried in situ concrete box some 23m long, 5.6m wide, and 7m deep below promenade level, accommodating intake and pump chambers with access from the promenade.

It was envisaged at tender stage that demolition of the demobilized chamber and construction of the new one would be carried out in a "dry" strutted cofferdam behind the existing seawall – a typical Hong Kong Government Portworks Department design some 40 years old, comprising large precast blocks on a rubble mound foundation.

As the existing structure comprised five precast pump chambers stitched together with an in situ superstructure, the contractor opted to repeat this idea for the new pump chamber and carry out demolition and reconstruction "in the wet".

As a consequence, the chamber was redesigned and detailed by Arup for the contractor as two large abutting precast open top boxes weighing some 280 and 320 tonnes.

21. Installation of precast seawater pump chamber by barge-mounted crane.

Stitching joint

Inevitably, structures founded on differing strata or with varying foundations will settle differentially. The running tunnel box structure beneath Salisbury Road is designed as a groundbearing raft within the superficial soil strata above rockhead. It also has substantial soil cover and hence is not liable to flotation. However, the station box partly supports above-ground structures, is partly supported on rock either directly or via piles, and has less soil cover. It therefore has different settlement and stiffness characteristics compared to the tunnel, which had to be allowed for during the various scenarios that occurred during construction, as the two structures were built by different contractors.

To allow for these settlement effects, a stitching joint was designed into the station/tunnel junction which also became the contract interface between the station and running tunnel contracts. The joint has an *Omega* seal fixed around it on the inside face of the tunnel box. The seal thus provided a watertight joint whilst the structures were backfilled at different times, and allowed for differential settlement. The specially designed and detailed joint was then concreted up at a later stage, prior to tracklaying, to allow as much settlement as possible to take place. The concreted "joint" now enables the structural box to resist any induced longitudinal bending due to residual settlement effects.

22. Station at foot of Signal Hill, with reprovisioned Middle Road children's playground at elevated deck level.

The existing structure was demolished to the level of the precast chambers, the stitch removed, and the precast units lifted out using a large crane barge. Once the old structure was removed, divers were employed to survey and prepare the new formation level underwater.

The new precast boxes were constructed on land adjoining the contractor's site office compound near Hung Hom station, just over 1km away by sea. They were then transported by barge and lifted into place using a 400 tonne lifting capacity jumbo crane barge (Fig 21). The remaining superstructure was built in situ above water level to stitch the units together. Co-operation between the designer, site team and contractor for this alternative approach proved to be a great success.

Conclusion

Following the contract commencement date of 12 March 2001 and ground-breaking on 20 April 2001, the station opening ceremony was held on the morning of 24 October 2004. Revenue operations commenced in the afternoon within the KCRC's original intention of opening the Tsim Sha Tsui Extension by the last quarter of 2004.

The design and design management of this highly complex station included intensive revisiting, review, and re-assessment of the original study for the Tsim Sha Tsui extension. And it led to a new alignment for the future connection between East Rail and West Rail now known as the Kowloon Southern Link.

The original KCRC concept of a curved side platform nine-car station had the significant environmental disbenefit of cutting back a part of Hong Kong's historical Signal Hill. Arup's design achieved what was at first considered unachievable: a straight island 12-car station with superior operational benefits to the KCRC, and a solution retaining in its entirety Signal Hill, which has benefited the community and the environment. With the completion of this new station, it is perhaps ironic to note that it is sited a mere 500m east of the original terminus that started its own operational life 90 years before.

Timothy Suen is a Director of Arup in Hong Kong, leader of the Hong Kong Railway Group, and a member of the firm's global rail and infrastructure boards. He was Project Manager for the Tsim Sha Tsui extension and acted as the Engineer. He was also Project Manager for the Kowloon Southern Link feasibility study.

This is an abridged and updated version of a paper that gained second prize in the Hong Kong Institution of Engineers Civil Engineering Paper of the Year Awards for 2004.

Reference

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East Tsim Sha Tsui station elevated decks:

reprovisioning and improving for the community

Timothy Suen Colin Wade

Introduction

The government's proposed locations for the station in its various studies were extremely limited, due to Kowloon Peninsula being already highly developed and crowded. Choices were either immediately below roads or beneath public land, such as parks or a government-owned multistorey car park, so the choice of building under the two open spaces of Middle Road children's playground and Wing On Plaza garden was fairly obvious. However, in temporarily removing these tracts of well-used public green spaces, the KCRC was committed to reprovisioning, and the requirements were agreed by the KCRC and the Government's Leisure and Cultural Services Department as end user.

Middle Road children's playground

The deck over the main station entrance and vehicle drop-off and general servicing area is elevated some 9m above street level to provide clearance to double-deck buses. Copious planting was incorporated and so the soil loading requirements were high - its depth up to 2.5m, which led to combined superimposed dead and live loads of up to 66kPa in many areas. Due to the vehicle swept-path requirements and bus bay layout, the column locations resulted in long spans and large loads in some places. Column locations were also severely constrained by the fact that highly sensitive telecommunications cables were buried across the site. These could not be moved.

The deck structure is a two-way main beam system between columns, acting as sway frames with a two-way coffered slab arrangement.

Garden amenities on the deck include toilets, a small sales kiosk, children's play area, shaded seating areas, and a small management block. Access is via sets of stairs plus a lift near the main station entrance. The separate service lift is set apart from the bus bay area, as truck access is needed for landscape maintenance, pruning, waste removal, etc.

Wing On Plaza garden

In mid-2002, well into station construction, the Government's Transport Department proposed building a public transport interchange (PTI) on the site. This effectively required abandoning the reprovisioning of the garden as originally designed and finding another solution – either no garden at all or a full reprovision using an elevated deck similar to the one at Middle Road children's playground. Two new footbridges were also proposed, one across Chatham Road South linking the two decks, and another over Salisbury Road to access the harbourside promenade; this was being upgraded due to the new railway tunnel construction under Salisbury Road.

1. Wing On Plaza garden deck. On the left is the vent structure serving the public transport interchange below.

2. Salisbury Road access bridge.

Arup was commissioned by the KCRC, acting as the government's agent, to carry out a rapid feasibility study of buildable options that would not affect the station construction or its opening date.

The Transport Department required double-deck bus access and numerous bus bays, lay-over parking zones, plus the necessary manoeuvring requirements. Coupled with the existing external road layout this greatly constrained available schemes for providing a covered space unless very large deep structures were adopted that would span clear of the station structure to avoid overloading it.

As well as the station substructure, the site constraints are considerable and gave very little scope for reproviding a very heavy elevated deck without supporting it directly on the station and causing significant disruption to the on-going construction. These constraints were a large plantroom superstructure to the south-east serving the station but with no more capacity for carrying extra load due to the already-built station substructure beneath, to the north-east a drainage reserve and buried seawater cooling pipes that prevented any new foundations being built, and to the north-west, a strip of large mature trees on Chatham Road South that severely restricted the location of any new foundations.

For the PTI itself, numerous schemes were investigated including minimalist roof canopies, partial open roofs, full long-span roofs, and, to satisfy the need to reprovision the original garden, a full impervious landscaped deck. Only the latter catered for wholly replacing the garden, but was the most difficult to engineer without in some way affecting the station construction either physically or programme-wise.

As ideas developed, it became apparent that even if new foundations could be built around the perimeter of the station in some discrete locations, the resulting clear spans across the "no-go" station box would not be practical for a structure carrying heavy landscaping. Ideas to gain support from the station were thus vital. As noted on p10, the station concourse roof was designed to carry some 3m-4m of backfill so as to reprovide soil cover for the original garden. The preferred scenario was to delete the backfill, provide a suspended road slab at ground level for the PTI, and leave the remaining gap above the station roof as a void. The resulting net weight saving was thus available to be offset against the weight of the deck. To support the deck, new columns directly above the station columns would be used wherever possible. As a contingency it was proposed that the capacity of all station columns not yet built should be increased by adding extra reinforcement, so that spare foundation capacity could also be used wherever necessary.

The footbridges were initially schemed with a view to upgrading this part of Tsim Sha Tsui with iconic solutions that would enhance the area in line with the government's aim to improve this under-utilized and low amenity promenade. The schemes included shaped walk-through truss types, large span arches, and cable-stayed structures.

In September 2002 Arup submitted a comprehensive feasibility report with recommendations. A most important issue was to gain agreement to strengthen station columns and delete the backfill above the concourse box as contingencies against the scheme not commencing immediately. This was accepted and the necessary changes made - a correct decision as the scheme underwent a long development with numerous presentations to government agencies before acceptance in its final built form.

Final solution

Substructure

This followed the concept of providing a "voided" structure directly above the station roof. A 2.5m deep cellular structure with top and bottom slabs and numerous parallel in situ concrete walls forms a series of cells. Interspersed among them are 2.5m deep transfer beams carrying some of the landscaped deck support columns onto those station columns that were specifically strengthened. The cells have access and drainage sumps for maintenance and inspection.

Superstructure

This is a grid of long-span (up to 29m) main support beams in two directions on the irregular column layout with intermediate one-way spanning beams. An in situ deck slab carries all landscaping planters, shade structures, seating, and a large specially featured vent structure serving the PTI below. Matching the 9m height of the opposite deck, access is by stairs, an escalator, and a lift from a subsidiary station entrance.

Chatham Road South access bridge

This connects the two decks across the very busy junction of Salisbury Road and Chatham Road South, and carries some electrical/mechanical services and edge planters. The bridge widens in plan from 10m at the Middle Road playground side to some 23m at the Wing On Plaza side.

To visually tie in with the landscaped decks a truss or walk-through structure was inappropriate, so a simple in situ concrete deck was adopted. Due to the heavy planter loading, a clear span (some 45m) between the two sides was impossible to achieve within the headroom constraints, so two oval-shaped columns were placed in the central carriageway divider, leading to two very sharply skewed spans for the bridge. The deck is a double slab with concealed beams and the edge planters contained in upwardly tapering wings.

Salisbury Road access bridge

This bridge underwent considerable scheme development following on from the iconic ideas presented at feasibility stage. To incorporate an escalator and stair within its width at the harbour promenade, its deck also widens in plan, from some 7m at Wing On Plaza garden to 16m at the promenade. A truss-type solution could not have incorporated the stair and escalator in a visually attractive way, so after much debate on the deck form and the shape and location of supports, a simple reinforced concrete deck slab supported by twin steel box girders with tapering sides was adopted. Cast in situ vertical piers either side of the Salisbury Road carriageways carry the girders – twin piers flanking the stair and escalator void and a single pier adjoining the landscaped deck side. This gave a 56.5m main span, with a 15m cantilever beyond the harbour-side piers to form a large viewing deck.

3. Middle Road children's playground.

4. Wing On Plaza garden from above, with Chatham Road South access bridge to bottom right.

Construction

Station completion and handover were not compromised by these new works and the KCRC successfully negotiated a supplemental agreement with the same contractor to carry out what was effectively a new project. Work commenced in November 2005 within its own secure area, without affecting station users. The Chatham Road footbridge deck was built on falsework over the carriageways without need for road closures. The Salisbury Road footbridge box girders were fabricated in Guangzhou and barged to an intermediate yard in the New Territories. From there, they were delivered in sections and lifted onto temporary supports placed on the carriageways and welded together during five night-time road closures. The work was completed and handed over to the end user in June 2007, and it both functionally and visually complements the Middle Road deck above the station.

The government has also built an al-fresco dining facility on the promenade close to the Salisbury Road footbridge, further enhancing the popularity of this harbourside amenity.

Conclusion

The reprovisioning project involved a multi-disciplinary Arup planning and design team working closely with the station/deck architect and landscape consultant, and with several difficult constraints. Usage and accessibility of the harbour promenade have been enhanced by the new footbridges, one of them now forming a viewing deck to Victoria Harbour. With the completion of the PTI, more direct bus linkage with the KCRC's rail network has also been gained.

Pedestrian subways for East Tsim Sha Tsui station:

planning and construction

Stephen Hope Julian Wright

Introduction

With the aim of rejuvenating the East Tsim Sha Tsui area, the Government requested that the subway system be extended to improve accessibility and user comfort through the heart of one of Hong Kong's busiest tourist areas.

It thus grew from a relatively simple, high-capacity, station interchange between East Tsim Sha Tsui station and the MTRC's nearby Tsim Sha Tsui station to an extensive pedestrian network almost 900m long, fully integrated with adjacent retail developments, serving rail and non-rail users alike. It was also widened to add moving walkways, and integrate with a 250m-tall urban regeneration project nearby, also designed by Arup.

Linking areas west of Nathan Road to those east of Chatham Road South (Fig 1), the fully air-conditioned subway network gives pedestrians numerous route choices, relieves at-grade footways, and complements the Government's pedestrianization initiatives for the district. The volume of people using the subway, and the highly urbanized nature of the route, created significant design challenges in optimizing width with buildability.

1. Layout of the subway network.

Planning

Planning and sizing the subway network was determined by the feasibility of route alignments, the physical width of construction corridors, and patronage demand. Users were categorized as: (1) rail-to-rail interchange passengers, (2) rail-to-street passengers, and (3) non-rail street-to-street pedestrians.

While the forecasts of rail passenger demand for East Tsim Sha Tsui station and interchange were provided by the KCRC, the usage of the subway by non-rail pedestrians, assignment of all users, and ultimately the size and configuration of the subways were determined by Arup during the design.

Rail forecasts

As a terminus station, East Tsim Sha Tsui currently accommodates 12-car East Rail trains. It was proposed that, on completion of the Kowloon Southern Link, Hung Hom station would become the terminus for both the East Rail and West Rail systems, with East Tsim Sha Tsui operating as an intermediate station.

Peak hour passenger movements through East Tsim Sha Tsui station were forecast to be greatest by the design year of 2011, and then reduce when the Kowloon Southern Link opens. By then the typical morning rush hour passing through both East Tsim Sha Tsui and Tsim Sha Tsui stations and the associated subway network is forecast to reach 68 000 passengers. This number was critical for the design.

Non-rail forecasts

The team built a model to simulate non-rail pedestrian demand passing through the subway, and to derive the corresponding assignment of rail passengers. The model was developed and calibrated using pedestrian link counts, inventory surveys, and origin and destination (OD) surveys across the study area.

Pedestrian link counts were undertaken at 44 locations, and OD surveys at 13 sites based on a 39-zone system. Interviewees were categorized as Hong Kong residents or visitors, and asked to confirm trip purpose, transport mode, origin, and destination zones. Inventory surveyors were used to define the streetscape environment within the simulation model, affecting journey times and ultimately route choice.

Several major mixed-use developments were committed close to the subway. Trip generation and mode split for these were combined with the survey data to develop non-rail trip matrices within the model for morning, evening, and off-peak hours.

2. Kowloon Hotel subway entrance at night.

3. The completed subway at the junction of Mody Road, Hanoi Road, and Blenheim Avenue.

Model development

As well as forecasting total daily usage of the subway system, the model was used to assess and then support the need for further extensions. Variations to the baseline scenario were reviewed to assess the sensitivity of pedestrian route choice to network extensions, which in turn was used to evaluate their economic viability.

Accurate representation of congestion effects on pedestrian route choice was the key modelling parameter influencing the diversion rates of non-rail usage to the new subway network. As such, much time was spent on calibrating the model to existing pedestrian movements and local street congestion. Similarly, substantial effort was spent on ensuring the model gave a true reflection of congestion levels resulting from the high volume of rail passengers passing through the distinct elements of the subway, including travelators, stairs and escalators. Key aspects of the model development were network coding, matrix construction, speed/flow relationships, assignment methodology, and calibration and validation.

(1) Network coding: Model calibration for the 1999 base year network included all pedestrian links within the study area classified by width, usage, type, and condition; most of the network comprised footpaths, classified as primary and secondary. "Secondary footpaths" represented alleyways between buildings within the same city block; while generally these experience low usage, some give access to markets, restaurants, retail outlets, or form useful shortcuts when the primary footpaths become congested.

Footpaths were subject to volume/delay functions based on speed/density relationships. In some instances their absolute capacity was difficult to quantify, with, during severe congestion, some pedestrians choosing to walk in the road alongside, although at the more critical junctions many of the footpaths have pedestrian guardrails. These were subsequently adopted in the model.

While all footpaths were coded as bi-directional links, the assignment procedures within the model took account of dominant pedestrian flows in one direction, with the capacity in the opposite direction reduced to reflect actual street conditions.

Pedestrian crossings were classified into signalized, non-signalized, and jaywalking movements. Signalized crossings incurred delays based on the cycle time of the traffic lights - an average delay corresponding to half the traffic phase. Non-signalized crossings were modelled with longer delays, based on pedestrian gap acceptance, vehicle traffic volumes and, where applicable, the "vehicle platoon" effect of nearby traffic lights. Mid-block jaywalking crossings were incorporated in the model, based on observed site conditions with delays derived from pedestrian gap acceptance criteria.

Stairs and escalators were coded separately with fixed capacities, attracting a rapid increase in delays when capacity was exceeded. Station passageways and concourses were included in the model, similarly coded to enclosed elevated walkways and subways, with non-paying parts of the concourse incorporated into the overall subway network accessible to non-rail pedestrians as well as rail passengers.

Future year networks were developed to include the station and the associated subway scenarios, committed nearby commercial development, and other proposed modifications to the pedestrian network included in the Government's 10-year transport works programme. The new travelators were coded in a similar way to escalator links, with fixed capacities based on width and operating speed.

(2) Matrix construction: A detailed questionnaire elicited travel patterns, including origins and destinations, and pedestrian characteristics, throughout the 39-zone study area. The survey divided the pedestrian sample into Hong Kong residents or non-residents, identified trip purpose as work, school, shopping, food, tourist, or other, and also determined mode of transport at journey start. In conjunction with link flow counts, these data were used to create trip demand matrices for non-rail work and non-rail non-work pedestrians. Local growth factors derived from a strategic transport

4. Pedestrian survey locations.

5. Levels of service at pedestrian links: "A" represents the least busy, and "F" is "congested".

6. Mody Road subway under Chatham Road South.

model of Hong Kong, together with new trips generated by nearby commercial developments, were used to develop matrices for appropriate forecast years. These, together with the rail-to-rail interchange and rail-to-street matrices attributed to the station construction, were used in the assignment process.

(3) Speed/flow relationships: These were based on two broad categories. "Open footpath relationships" are links without a physical boundary on one side, eg roadside pavements. These have higher capacities than those with boundaries on both sides, which experience increased delays based on pedestrian density.

"Closed footpath relationships" are links with physical boundaries on both sides, like escalators and elevated walkways. These have more rigid capacity limits, experience rapid increases in delays once capacity is exceeded, and frequently form the bottleneck in a pedestrian network. Values of speed/flow for these links were derived from previous studies of Hong Kong pedestrian characteristics, including those used to define the criteria for station design.

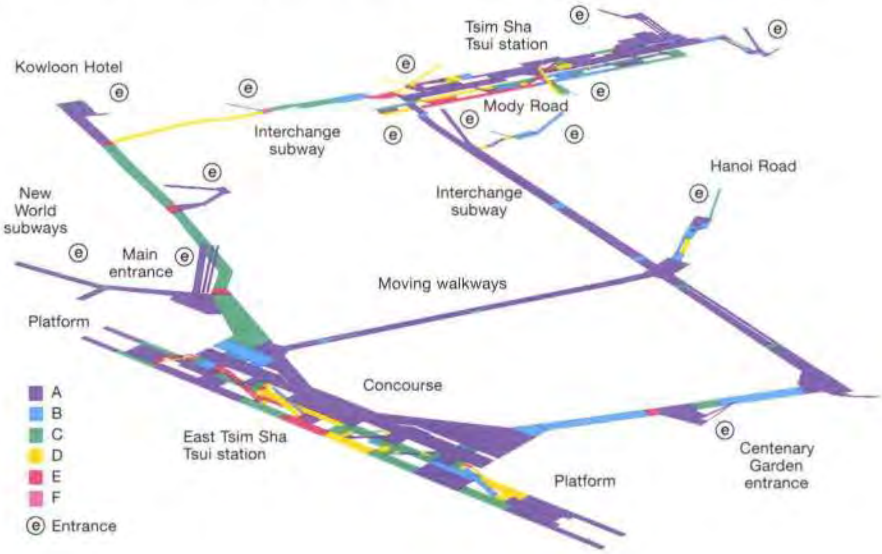
(4) Assignment methodology: The assignment procedure incorporated features unique to modelling bi-directional pedestrian flows. Initial assignments were used to model congestion effects, and the results then used to adjust the capacities on each link based on flow ratios, allowing dominant flows to be accurately represented. This process was repeated before the final model assignment, with some links becoming completely one-way as large pedestrian volumes dominated the link's full capacity, as was often observed during peak rush hours.

The assignment included four user types: rail interchange, rail-to-street, non-rail work, and non-rail non-work trips. For forecasting purposes the rail interchange trips were deemed to exclusively use the subway, the rail-to-street and non-rail work trips could use all links in the network, and non-rail non-work trips were restricted from using the rail-related links.

(5) Calibration and validation: The team compared results from the base year assignments with observed on-site pedestrian movements, link-by-link, throughout the study area, and the assigned flows were calibrated against the observed link flows for the morning, evening, and off-peak hours.

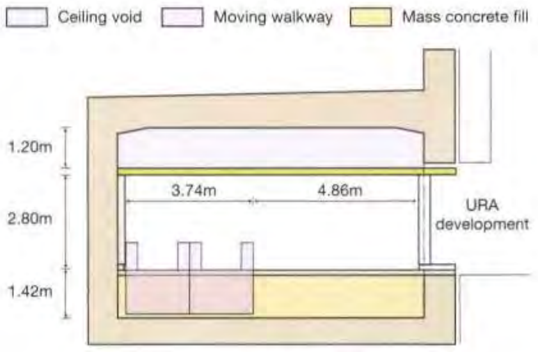
The high degree of correlation showed the calibrated model to be a robust design tool for forecasting future pedestrian behaviour within the study area. Also, many pedestrian survey locations around the network were monitored (Fig 4). From all this data the levels of service were obtained for the pedestrian links around the study area (Fig 5).

7. The moving walkway at Mody Road subway, adjoining the URA development site (also an Arup project).

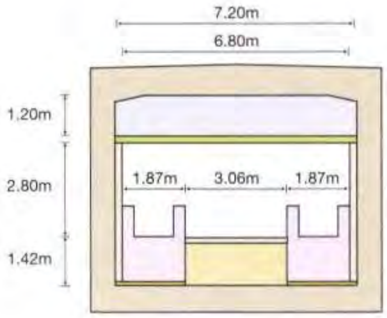


8. Levels of service of subway network: "A" represents the least busy, and "F" is "congested".

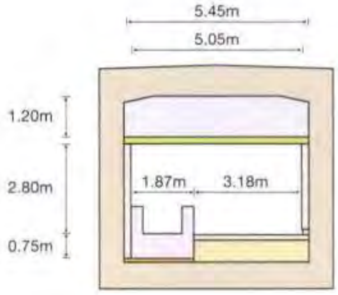
9. Typical cross-sections.



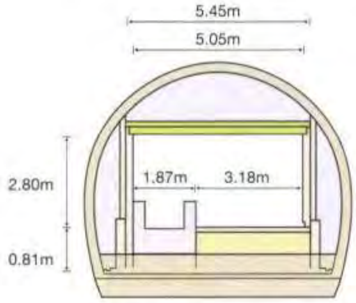
Typical section through Mody Road (Western side)



Typical section through Mody Road (Eastern side)



Typical section through Blenheim Avenue



Typical section through Signal Hill

Subway sizing

A design year forecast for rail and non-rail pedestrians was generated for each part of the subway, to determine the optimum network configuration and operational arrangement. The anticipated levels of service for morning, evening, and off-peak hours were reviewed against design criteria and the volume/capacity ratio of each subway section and entrance point assessed to identify bottlenecks and operational deficiencies. This allowed the design to be refined in terms of overall internal clear width, peak hour pedestrian management, and the provision of horizontal and vertical circulation. In consultation with the geotechnical and structural engineers, the team then evaluated the optimum planned design for buildability and economic viability before proceeding to detailed design and construction. Based on the survey information, the service level for the subway network was obtained (Fig 8).

Construction

The subway has three main elements. The first runs beneath Mody Road and Hanoi Road, connecting westwards to the MTRC Tsim Sha Tsui station concourse and eastwards to the KCRC East Tsim Sha Tsui station concourse. Seven moving walkways aid pedestrian movement along this Mody Road section, which including the Hanoi Road entrance spur is some 450m long.

The section beneath Blenheim Avenue and Signal Hill connects at its north end to the Mody Road section and at the south to the KCR station concourse. It is about 180m long, contains two moving walkways, and includes a bored tunnel section beneath Signal Hill. The third section, c250m long, extends under Middle Road, passes below Nathan Road, and connects into the Kowloon Hotel.

The patronage forecasts and pedestrian planning study showed that the subway needed to be as wide as possible (Fig 9), so its permanent sidewalls were located right up to (and in some areas beyond) the existing kerb lines.

10. Utility supports under Mody Road temporary decking.

11. Mini pipe piling rig in Mody Road.

12. Giken *SC100 Super Crush Piler* in Mody Road.

Indirect technical remedies

Before construction, the KCRC provided what were termed "indirect technical remedies" (ITRs) in the form of upgraded glazing and air-conditioners to buildings where the residual noise levels during construction were predicted to exceed 75dBA by >5dBA for over a month. Installation of relevant ITRs was completed four weeks before construction of that subway section began. Their use was unusual for this type of project but may become more common, given Hong Kong's increased awareness of environmental issues.

The KCRC could not force people to fit ITRs, so their implementation relied on the co-operation of many individual owners and tenants of the residential premises around the subway routes. Arup was asked to:

- predict which premises were likely to exceed the noise criteria during construction
- survey all premises likely to exceed the noise criteria and record all relevant observations related to ITR works
- based on the results of the survey, determine the cost of implementing ITRs for each residential unit and an overall budget for all affected premises
- write a report with all survey results, budget, recommendations, and action plan for implementation of the ITR work
- supervise installation of recommended ITRs
- monitor acoustic results during construction to ensure compatibility with initial assumptions.

Two teams, each comprising an electrical, a mechanical, and a structural engineer, gathered the required information in surveys scheduled at <20 minutes per apartment, and with minimum disruption to residents.

Existing steel-framed windows needed to be removed and new ones installed. If the windows were of aluminium, a thicker glass pane was installed to meet the environmental requirements. The general condition of the structure supporting the windows was also visually inspected in each survey, and a general provision made for structures that required modification to install the new window frames.

The surveys also covered air-conditioning requirements in apartments along the affected façades. The cooling load of each room was calculated and from this figure an appropriate commercially-available air-conditioning unit (ACU) was selected, and the required electrical power derived from its size. Where ACUs were already in place, their condition was checked and the room dimensions and window sizes recorded to calculate electrical running costs and determine whether or not the power supply would be sufficient to support additional ACUs to the affected apartments. The assessment also extended to the power distribution system and main overall supply in the building to ensure it would sustain the demand increase.

The electrical installation assessment was in two parts: (a) each apartment and (b) the building as a whole. A total of 470 apartments were visited over six weeks and 292 were successfully surveyed – a 62% success rate achieved through the survey teams' persistence and diplomacy.

Cut-and-cover temporary works

The subway network mostly had to be built by cut-and-cover techniques – and this through one of Hong Kong's major tourist areas. Extensive temporary traffic management arrangements, and utility diversions and supports (Fig 10), were needed, as well as careful public relations with local shop owners and the general public. Given Tsim Sha Tsui's location, these issues required significant input at both the detail design and construction stages to resolve the numerous logistical problems.

To maximize subway widths, the temporary works (pipe piles or sheet piles) were located in the footpaths as close as practicable to the building line of existing structures. In some places, overhanging canopies of existing buildings imposed additional constraints, requiring the use of a mini pipe piling rig (Fig 11).

The subway structure design had to take account of the stability of adjacent buildings, which vary in age, quality, height, and foundation type.

Existing building information was obtained from the Government's Buildings Department, and foundation types and structural layouts studied in detail to determine if there would be any adverse effects. All existing buildings were monitored during construction and no adverse movements were recorded.

Generally, pipe piles were installed where core stones were anticipated or the rockhead found to be high. Where fill and completely decomposed granite were anticipated the contractor installed sheet piles with a Giken *SC100 Super Crush Piler* (Fig 12), which pushes the sheet piles into position using a reaction force from previously installed sheet piles. It had been used successfully in Singapore, but this was the first Hong Kong project to use this type of machine. It proved to be particularly quiet, and installed sheet piles to within 1m of existing buildings. Where stiff, completely decomposed, granite was encountered, an integral auger system within the Giken *Piler* was available to pre-drill through the denser material to allow subsequent penetration of the sheet pile.

13. Excavation beneath the road deck.

14. Signal Hill tunnel excavation.

15. Lining to completed Signal Hill tunnel.

As soon as the temporary pipe pile or sheet pile retaining system was in place, a deck was installed spanning the full width of the road between the temporary retaining walls. Excavation then proceeded beneath the deck using a modified tunnelling technique from dedicated access locations (Fig 13). This ensured minimum disturbance to traffic flow.

Signal Hill tunnel

The section of Blenheim Avenue subway under Signal Hill was designed and built as a horseshoe-shaped rock tunnel with a flat invert. The portal was formed at the station site in Middle Road Playground and the tunnel then excavated towards a small shaft in Blenheim Avenue. This section is some 110m long, and the excavated diameter around 8.8m, with a 7.4m finished internal concrete lining (Fig 15).

The tunnel was generally excavated by drill-and-blast (Fig 14), with a blast protection door at the portal to stop fly rock entering the main station site or crossing to Salisbury Road beyond. The charge of explosive per delay was estimated based on specified peak particle velocity (PPV), limited by several sensitive receivers around the site. The PPV limits were controlled by adjacent slopes (maximum PPV 6mm/s) and the historic tower on top of Signal Hill (13mm/s), with all other existing structures limited to a PPV of 25mm/s. Signal Hill Tower was monitored throughout construction and suffered no ill effects from the excavation.

The installed temporary support generally comprised rock bolts and shotcrete. Close to the portal there is limited rock cover and here steel arch rib supports at 1m centres with a protective canopy of horizontal pipe piles were used. In areas of soft ground, a top heading was advanced for installation of the top section of steel ribs, followed by the bottom bench and completion of the arch. The lining shutter was 6m long, and the shutter formwork was removed about 12 hours after completion of concrete placement, when it had reached the minimum approved working strength.

16. Initial excavation and decking supports for Nathan Road crossing.

Nathan Road crossing

Construction of the Middle Road subway section crossed Nathan Road, the main north-south traffic artery through Tsim Sha Tsui (Fig 16). This had several significant constraints, including:

- telephone company manholes (4.5m x 4m x 4.4m deep) and associated sensitive fibre optic cables that could not be relocated
- a 1.5m x 2m wide main stormwater drainage box culvert running along Nathan Road
- two 5m internal diameter MTRC Tsuen Wan Line (TWL) running tunnels beneath Nathan Road
- two 500mm diameter mains supplying cooling water to air-condition MTRC's Tsim Sha Tsui station
- the Highways Department permitting closure of only one lane at a time.

The maximum available clearance between the TWL running tunnels and base of the main drainage culvert was about 10m. Also, the MTRC required a minimum 2m clearance between any temporary works and their running tunnels. To allow the subway tunnel to pass through the tight gap, the height of the subway box in the crossing area was reduced by limiting the E&M services there.

The temporary works in the crossing area consisted of a propped pipe pile retaining wall. Due to the limit on lane closures, eight stages of temporary traffic management were required to install the pipe piles across Nathan Road. Immediately after each pipe pile section was installed, a temporary traffic deck was placed to carry the traffic and allow installation of the next section. Subsequent excavation was carried out by "tunnelling" beneath the decking from each side of Nathan Road, working towards the centre and installing props as the excavation progressed.

Over the TWL running tunnels, the pipe pile depth was limited, and required toe stability to be improved by a jet grouted raft at the base of the excavation. This raft was carefully installed to ensure that excess pressure was not exerted on the running tunnels.

An extensive finite element model of the crossing area, including the TWL running tunnels, was prepared to show the stresses and deflections in the running tunnels at each construction stage. Approval of the model and the results was obtained from the MTRC prior to works commencing.

Extensive real time instrumentation arrays were installed in the TWL running tunnels to monitor deflections and changes to tunnel shape during the works. The crossing was built with no adverse effect on the structure of the existing tunnels, and no effect on the MTR railway service.

Conclusion

Planning this subway network had to take into account the varied and dense urban texture of the Tsim Sha Tsui district – still, perhaps, the consistently busiest tourist area in Hong Kong. From pedestrian modelling, sizing and design, through construction planning and finally, execution, it was a challenging piece of infrastructure.

Collaboration between the KCRC, designer and contractor, and the Corporation's foresight in setting up a neighbourhood and public liaison team, brought the project to completion with few serious complaints. The result has clearly improved the crowded streets in the vicinity and gives commuters and other users a clean, air-conditioned, and generously-proportioned link with conveniently placed entrances (Fig 17) between two busy stations on Hong Kong's rail network.

17. Entrance to subway in Mody Road.

Stephen Hope is an Associate Director of Arup in Hong Kong. He was Project Manager for the Tsim Sha Tsui subway network.

Julian Wright was formerly an Associate of Arup in Hong Kong, now with the Hong Kong Jockey Club. He was responsible for pedestrian flow modelling for the subway network.

The Tsim Sha Tsui extension railway tunnel:

engineering planning, design, and construction

Julian Hill SS Kong Patrick Ng Timothy Suen

Introduction

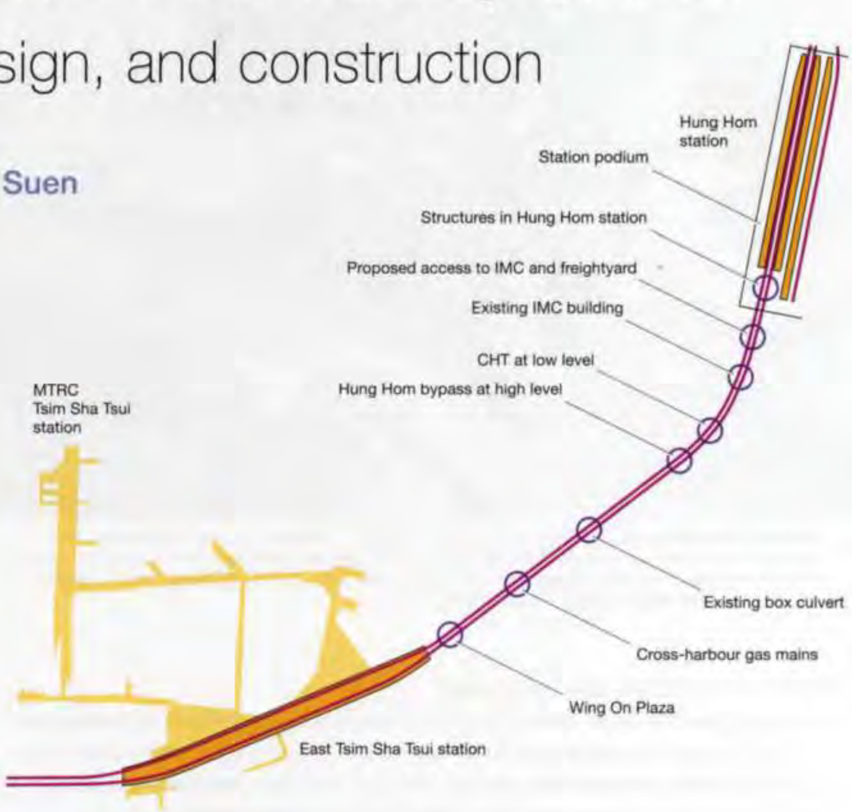
The running tunnel portion of the Tsim Sha Tsui extension was a complex piece of civil engineering construction, extending the domestic urban rail service from the southern end of the Hung Hom station podium to the interface with East Tsim Sha Tsui station. The contract area covered a 600m length of this very busy part of Salisbury Road, which in this section fronts Victoria Harbour. The planning, design, and construction included several challenges for what, superficially, is a simple rectangular concrete tube containing twin railway tracks.

Planning and design

Railway alignment and tunnel route constraints

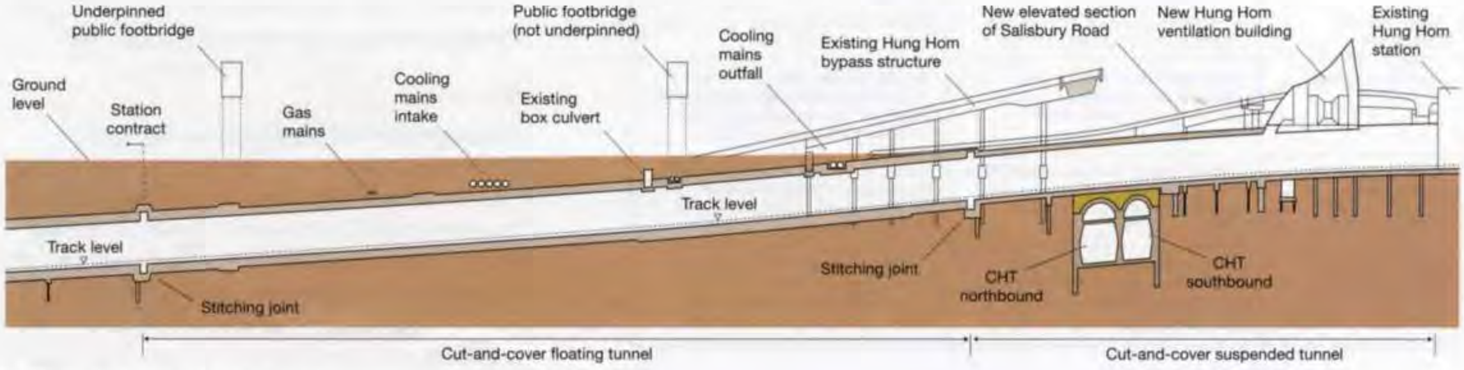
On leaving Hung Hom station the alignment enters a box structure with a tight horizontal curve as it descends to pass close to the International Mail Centre (IMC). The tunnel box passes over Hong Kong's first cross-harbour road tunnel (CHT) by less than 500mm and fits tightly between the piers of the Hung Hom bypass, an elevated road completed a few years earlier.

It then continues to descend at a maximum 3% gradient under Salisbury Road, passing beneath several utilities with minimal clearance. The tunnel runs parallel to the sea wall of Victoria Harbour, roughly 10m back from the face, and the alignment curves opposite Wing On Plaza, where the box widens to allow a central wall between the tracks, to East Tsim Sha Tsui station (Fig 1).

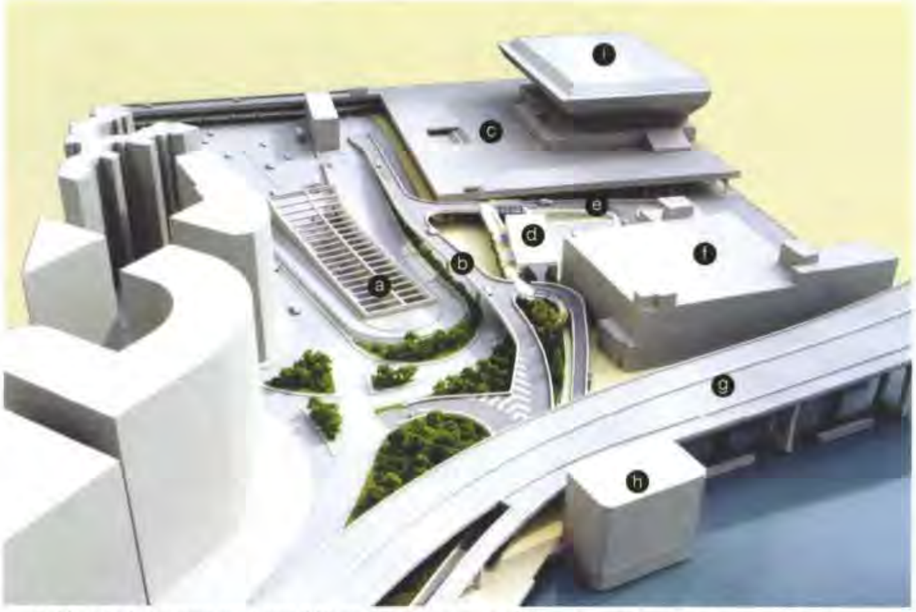


1. Railway alignment and tunnel route constraints.

Once clear of Hung Hom station podium, the extension runs through a short open section between podium and tunnel to ensure the two structures act independently for ventilation and emergency escape. Due to the severe physical constraints along Salisbury Road, a minimum-width, twin-track, single-cell box tunnel was developed without the usual central dividing wall. The vertical clearance from top of rail to roof soffit is 5.6m, except in short sections where it reduces to 5.2m, with local recesses in the roof slab to overcome critical constraints such as gas mains, a box culvert and cooling mains. The vertical alignment is constrained by crossing over the CHT, the utilities under Salisbury Road - particularly the cross-harbour gas mains, box culvert and private cooling mains (Fig 2) - the new Salisbury Road underpass structure at the Chatham Road South junction, and East Tsim Sha Tsui station, itself constrained by future West Rail requirements.



2. Longitudinal section (not to scale).



3. Model of elevated road and IMC enabling works: (a) CHT exit/entry ramp, (b) new elevated section of Salisbury Road and access to IMC and freightyard, (c) Hung Hom station, (d) new KCRC ventilation building, (e) to KCRC freightyard and IMC, (f) IMC, (g) Hung Hom bypass, (h) CHT vent building, (i) Hong Kong Coliseum.

The contract HCC301 works comprised:

- a 600m cut-and-cover tunnel, generally 10m wide by up to 6.8m high internally: formation level varying from 3.5m below ground at Hung Hom station interface to 18m below ground at the contract interface with East Tsim Sha Tsui station
- a 250m section of the tunnel box partially exposed above ground with a substantial ventilation building built directly over it
- an elevated road system to the IMC and KCRC freightyard (Figs 3, 4), with a 3m x 3m cut-and-cover cable tunnel for China Light & Power Co Ltd crossing below the railway
- underpinning of a public footbridge opposite the Shangri-La Hotel (Fig 5).

During detailed design development several issues in the original feasibility study were revisited and re-engineered with cost and programme benefits accruing to the KCRC (Table 1).

Table 1. Major constraints and design development

Major constraints	Railway development study/technical study phases	Detailed design phase
Enabling works at IMC for access to IMC and KCRC freightyard	New bridges, platform over harbour with marine pilings, and demolition of IMC jetties.	Access rearranged at Hung Hom station podium edge, all marine works avoided, but the KCRC train crew centre demolished and relocated.
Cross-harbour road tunnel	Potentially massive transfer slab cast directly on top of existing CHT roof.	Ballast trough with tunnel bridging over (Fig 6).
Hung Hom bypass	Excavation close to foundations, with overhanging bridge deck to be demolished and reconstructed afterwards.	No change during design; however, contractor used specially adapted plant in areas of low headroom, avoiding demolition of bypass deck (Fig 8).
Cooling water mains and box culvert	Major diversions of all cross-road intake mains; objections from owners, risk of delay to the railway project with disruptions to traffic.	Intake mains diversions avoided with tunnel alignment steeper than the maximum 2.5%; objections resolved and programme risks minimized.
Cross-harbour gas main (serving over 200 000 households on Hong Kong Island)	Seriousness of conflict with tunnel depended on exact levels, which were difficult to determine; diversion if required would take 18 months.	Trial holes not possible, due to being over 5m deep near waterfront promenade; steepened gradient of tracks slightly reduced conflict risk.

Geotechnics and foundations

The site was reclaimed in the 1960s to form the district now known as Tsim Sha Tsui East. Site investigation revealed ground conditions to be fill (8-14m) overlaying marine deposits (0-15m), which in turn were above alluvial deposits overlaying different grades of weathered rock. The thickness of the marine and alluvial deposits reduce towards the eastern end of the tunnel. The rockhead level generally drops from 20m below ground at the northern end of the tunnel at Hung Hom station to some 43m at the south-western end.

An end-bearing foundation was required under the first 220m of tunnel from Hung Hom station, due to the permanent design requirements of spanning the tunnel over the CHT and supporting the integrated ventilation building. There are 26 straight-shafted concrete bored piles, generally 2m in diameter, and due to the height restraints under the Hung Hom bypass, 34 pre-bored H-piles west of the CHT. The remaining 380m of tunnel acts as a ground-supported raft with stitch joints at either end.

Private cooling water mains

Originally, all seven intake cooling mains serving nearby hotels and commercial buildings were affected by the new railway. All the owners lodged objections, as their air-conditioning would be affected and they would have to bear the costs under their lease agreement with the government.

This was a major risk to the construction sequence and programme, so during detailed design the project team successfully worked with the KCRC Operations Department team to increase the track gradient from 2.5% (the design maximum) to 3% for a short length without compromising emergency operations should a failed train need to be pushed up the gradient by another. This enabled the tunnel box to be built at a greater depth and avoided diversions to most of the intake cooling mains, with the outfall cooling mains only requiring local diversions. The objections were thus resolved with the owners also entrusting the diversion works to KCRC - a win-win situation that minimized their costs and reduced the risk to the programme.

Box culvert

Steepening the rail alignment also avoided the need to divert a 2.6m x 2.5m deep box culvert maintained by the Government's Drainage Services Department (DSD). As a result, however, its base had to be formed as part of the tunnel roof slab and its walls cast monolithically with the tunnel roof. Although undesirable and abnormal for structures under different ownership (KCRC and DSD) to be combined, this case could not be avoided.

Cost-effectiveness and innovation

Design reviews and value engineering workshops with KCRC and other stakeholders were carried out regularly during the scheme and detailed design stages. Arup's innovative ideas were welcomed by the KCRC, entrustors, and the contractor for cost-effectiveness and programme certainty. The following are two examples.

International Mail Centre (IMC) access

The original preliminary design carried out by others during the Technical Study stage proposed a new elevated access road to the IMC with a seaward alignment across the Hung Hom waterfront. This would have had serious environmental impact. It required submission to the Port Works and Marine Departments of the government as well as the Advisory Committee on the Appearance of Bridges and Associated Structures. This had inherent serious approval risk and therefore programme risk. Arup reworked this scheme with a landward route and redesigned part of the existing road network to include a section of new flyover connecting to the IMC. As a result, Arup eliminated delay to the programme and achieved a reduced construction cost with no marine or environmental impact.

4. New elevated access road to IMC and freightyard.

Drainage pipes through seawall

For Contract 301, Arup, the KCRC ,and Gammon Skanska Ltd signed a voluntary partnering charter whereby value engineering workshops were held post-contract award. New entrusted works were instructed by KCRC on behalf of the DSD to provide three 1.05m diameter drainage outfall pipes through the existing seawall. The contractor proposed a temporary cofferdam built in the harbour to remove part of the existing seawall and replace it with a new precast section incorporating the drainage pipes. Again, these works required approval by both Marine and Port Works Departments and would have resulted in programme risk. Arup proposed to construct a temporary cofferdam on the landward side of the wall to allow stitch coring of circular holes at low tide through the 2.7m thick precast seawall blocks. The drainage pipes were then inserted and grouted in. This method had not been tried before, but after a series of discussions with Gammon Skanska, a detailed method statement was agreed. This was accepted by Port Works (the seawall owners) without the need to involve the government Marine Department since no marine work was involved, and thus achieved a major cost saving with programme certainty. As a result of this successful and cost-effective method, DSD requested the contractor to form another three 1.05m diameter drainage pipes through the seawall as future provisions.

Environmental Impact Assessment (EIA)

Others had already carried out an EIA study, the railway extension being a designated project under Schedule 2 of the EIA Ordinance enacted in April 1998. The key environmental issues were the significant nuisance from construction, tree transplantation, and landscape and visual impacts.

Handling the 800 000m^3 of excavation materials for the three major, tightly-programmed, Tsim Sha Tsui extension contracts was a concern, as there would be up to 615 loaded truck movements per day, or 51 full trucks per hour.

A temporary marine platform opposite Wing On Plaza to access the construction sites was proposed, but the compromise solution was a barging point on the harbour at Hung Hom Bay reclamation just over 1km from the station site. To maintain water quality, good site management was important to control the slurries produced during bored piling and grouting, and so runoff was treated within the congested site without contaminating the adjacent harbour.

The EIA's performance commitments were incorporated through the detailed design, tenders, and construction, with a comprehensive environmental monitoring and audit programme, and an environmental management plan.

Public consultations and public relations

The whole Tsim Sha Tsui extension scheme, including the station itself as well as the tunnels, was formally published for public consultation in April 1999 under the Railways Ordinance and objections were handled by the government together with the KCRC. Issues of concern were trees, the impact on shops and hotel operations (in particular their private seawater cooling mains systems, as noted above), environmental issues, traffic, the need for the waterfront promenade to remain open, hoardings, and visual and site tidiness in a tourist area.

Extensive consultations were held with the District Board, Area Committee, former Provisional Urban Council, and local residents and hoteliers. The Railways Ordinance gives up to nine months, including a hearing, to resolve objections. In consequence, certain design changes and amendments were made before the Hong Kong Government's Executive Council authorized the scheme in 2000. A Tsim Sha Tsui East working group was formed with building owners and hoteliers to enhance communications.

Construction

Temporary traffic management

The proposed alignment of the cut-and-cover tunnel along the westbound carriageway of Salisbury Road was a major concern, and temporary traffic management (TTM) schemes were developed during the design stages. During construction, these schemes were approved and implemented through the site liaison group (SLG), a formal committee required for railway and public infrastructure projects to vet and approve temporary traffic arrangements.

For railway infrastructure work the SLG is chaired by the Government's Railway Development Office and, depending where the project is, can include a significant number of government agency representatives ranging from the police, fire services, transport department, and drainage services through to the departments responsible for leisure, culture, tourism and the postal services. SLGs are attended by the contractor, resident site staff, and design office representatives – a formidable meeting in most instances!

Salisbury Road's westbound carriageway had to divert north in phases, due to utility diversions and construction of the temporary tunnel retaining wall on the north side.

Negotiating all the approval procedures was a lengthy process, even for very minor diversions, and it was not until seven months after contract commencement that the major closure of Salisbury Road westbound was implemented and the works area fully occupied.

Utilities

Temporary relocation of sections of Salisbury Road westbound opened up access to the site. Along the line of the temporary tunnel retaining walls, trial trenches were excavated to locate utilities.

The project's urban location, and its proximity to the harbour, meant that every possible type of utility crossed the path of the cofferdam construction, including seawater cooling mains for four hotels and three commercial buildings; telephone cables with fibre optic cables for the Hong Kong Stock Exchange and Hong Kong Jockey Club; two gas mains supplying Hong Kong Island; 1.65m diameter stormwater outfall pipe; and box culvert stormwater outfall and power cables.

All these, except the gas mains, had to be temporarily or permanently diverted. The hoteliers required their cooling main diversions to be in the cool season between November and March, and the telephone company required 12 months to divert its fibre optic cables, with the Jockey Club cables diverted during the non-racing season.

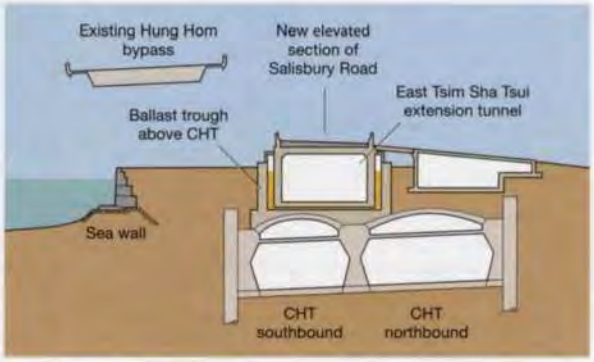
All this was executed by the relevant utility undertakers except the cooling main diversions, which were carried out by the main contractor as entrusted works. Interfacing the site works and access, therefore, became major issues.

Protection and monitoring of sensitive utilities and structures

Many sensitive structures were liable to be affected by excavation and dewatering during construction. These included two footbridges founded on friction piles, a gas control governor housed in a ground-bearing structure, the Hung Hom bypass and footbridge (both founded on end-bearing bored piles, but with bearings sensitive to differential movements), cooling mains pump houses, the CHT, the IMC, and all the utilities as previously described. A thorough geotechnical instrumentation monitoring system was thus needed as an early warning system. This allowed construction methods to be modified or additional preventive measures to be undertaken before any damage occurred. For example, the southern support for the pedestrian footbridge opposite the Shangri-La Hotel clashed with the proposed tunnel, so underpinning was adopted to transfer the loads to pre-bored H-piles outside the tunnel box. The footbridge remained open throughout (Fig 5).

The gas governor structure caused the most concern, as settlement exceeded the "alarm level" during the adjacent cofferdam construction. The ground was stabilized to minimize movement, and traffic was diverted as a temporary emergency measure. The pump test showed further settlement, and groundwater recharge wells were installed to maintain the external piezometric head and minimize settlement. Excavation of the cofferdam caused less settlement than the design predicted, but the temporary strutting opposite the gas governor was pre-loaded. The gas mains were regularly inspected by the Hong Kong and China Gas Company and no leaks or signs of distress were detected (Fig 7).

5. Underpinning of footbridge with transfer beams.



6. Cross-section of tunnel/ballast trough over the CHT.

7. Gas governor (behind hoarding on the left) and temporary support for cross-harbour gas mains.

8. Specially adapted rig to install pipe piles below the Hung Hom bypass.

Cofferdam construction

The contractor was responsible for the design of the temporary works. After much initial discussion, pipe piles - 24m long and 610mm diameter, at 710mm centres - were adopted as the preferred option to minimize disturbance to the surrounding ground. The rate of installation in areas with no height constraints was generally one pipe pile per day rig. On the north side of the temporary wall (away from the seawall), the auger method for installing pipe piles proved the most successful, with minimum disturbance to the surrounding ground.

At the design stage, partial demolition of the overhanging portion of the Hung Hom bypass deck was proposed, as only 3m of headroom existed, to permit construction of the temporary cofferdam wall. However, the contractor adapted a taller rig down to 5m height and with local excavation installed 406mm diameter pipe piles in 2m lengths welded together to form a temporary wall (Fig 8).

In the cusp of the pipe piles, tubes à manchette were installed with a grout curtain extending down to rockhead. The grout was pumped in two stages. First, to stiffen the ground a cement/bentonite mixture was forced in until the prescribed volume and pressure were reached. This generally took two shifts over consecutive days to complete as the fill and alluvia were sandy in nature. Then a sodium silicate chemical grout was pumped to fill the fissures in the stiffened ground.

10. Lagging installed ahead of main excavation to reduce risk of flooding.

9. The maximum four levels of struts at the western end of the excavation.

In the less-sensitive locations, sheet piles were faster to install and gave a more watertight cofferdam. Due to the constraints of phased TTM measures, utility diversions and the tight programme, cut-off walls were placed across the cofferdam to permit sections of it to locally be dewatered. During the pump test, excavation was permitted locally down to some 2m below ground level to help expedite construction, enabling the contractor to install the first level of temporary waling beams and struts.

Once the pump test was approved, bulk excavation commenced. The top level of struts also acted as supports to the temporary decking needed to facilitate the works, due to limited working space. The number of strut levels varied from one at the Hung Hom station end to four at the western end (Fig 9). The vertical spacing between struts varied between 3.5m and 4.5m, and they were generally placed at 6m centres along the tunnel box, supported by king posts down the centre of the excavation.

In places where utilities crossed the cofferdam, cement/bentonite was injected into the ground to seal gaps in the temporary wall below the utility. Lagging was also installed across the adjacent pipe pile/sheet pile wall above and below the utility. This reduced the excavation rate as it was needed after every 500mm of excavation to minimize risk of flooding (Fig 10).

Tunnel construction

After the final formation level was reached, blinding was cast, closely followed by the base slab. When the concrete had gained its design strength (usually after seven days), the lowest strut was removed.

Due to the tunnel box width and available space, the tunnel wall was cast against the temporary cofferdam wall, which was rendered out with a vertical layer of mass concrete between the pipe piles to form a relatively flat face. The level of the lowest waling beam and struts relative to the base slab reinforcement necessitated installing couplers to allow clearances to be maintained.

The tunnel box was waterproofed with a keyed preformed membrane beneath the base slab and behind the walls and a sprayed membrane was applied to the roof.

Cross-harbour tunnel

Hong Kong's first cross-harbour road tunnel was opened in 1972. It is a twin, circular steel, immersed tube structure for the main section beneath the harbour, reverting to a twin-cell, reinforced concrete box with arched roofs approximately 25m wide at landfall.

Where the new Tsim Sha Tsui extension tunnel crosses the CHT, the existing tunnel was constructed within temporary retaining walls comprising a mixture of contiguous bored piles with sealing piles behind them and contiguous peine piles (steel I-sections welded together at their flange tips to form stiff box sections). These were exposed and cut down to allow the new tunnel to cross them.

The design objectives were to: construct a tunnel to carry both rail and highway loading over the CHT; keep the railway tunnel and CHT independent of one another; limit the risk of damage to the CHT both during construction and permanently afterwards; satisfy buoyancy requirements for both the railway tunnel and CHT; and maintain a net downward load of 30kPa to mitigate any heave effects from the underlying completely decomposed granite.

Railway tunnel design

The innovative two-part solution that was adopted uses two separate structures:

(i) a reinforced concrete ballast trough, cast directly onto the roof of the CHT, to act as a passive weight, resisting net uplift

(ii) a reinforced concrete tunnel box, spanning 60m across the CHT and supporting the rail and highway loading. Piled foundations on either side of the CHT structure support the tunnel box.

The trough and running tunnel box are separated by a void. This both ensures that there is no loading from the tunnel onto the CHT and keeps the two tunnels independent. The base and walls of the ballast trough are relatively heavy (though much lighter than the transfer slab proposed in the technical study phase). To resist the maximum uplift pressures under permanent operational conditions, and to maintain the net downward load of 30kPa, additional uplift resistance was needed. This was achieved by filling the void between the ballast trough and tunnel box with water, which applies uniform pressure over the base of the ballast trough and arched roof of the CHT.

Monitoring and contingency plan

Another challenge was to prevent the CHT structure uplifting during excavation above it, and so four relief wells controlled by four monitoring wells were installed in the carriageways through its base. From in-depth analysis and sophisticated modelling of the existing and new tunnels and ground conditions, and with varying groundwater scenarios, the water level at all times had to be controlled within the specified range of 10.5m-11.5m below ground. If this was exceeded, an alarm system with auto-dialling to essential personnel would be activated for rapid site inspection and adjustment. The relief wells would release water pressure beneath the CHT structure by a simple valve, whilst the monitoring wells were vibrating wire pressure transducers with an electronic data acquisition device, which controlled the relief wells inside the CHT as 24-hour access was not permitted. Contingency plans were developed in intensive discussions with the CHT operator and the Government Highways and Transport Departments.

Throughout the critical construction period, the water level was successfully controlled within the design range. Deformation monitoring points closely monitored the CHT during the works and the maximum vertical movement observed was only 4mm, well within limits. The existing CHT roof was originally designed as twin bowstring arches, and so is very sensitive to any movement or imbalance in loading. Strain gauges, crack meters and a seismograph were used to closely monitor any movements, but from tight control of the works in this area nothing significant was observed.

11. Additional waterproof membrane applied to CHT roof.

12. Reinforcement fixed for ballast trough base slab.

13. Tunnel walls and roof cast monolithically.

14. The completed twin-track, single-compartment tunnel.

Construction sequence

(1) Construct permanent bored piles and pre-bored H-piles either side of CHT; build cofferdam; commence dewatering.

(2) Excavate and install first layer of struts; excavate to 0.0mPD (4.5m below existing ground).

(3) Activate CHT relief wells; excavate and install second layer of struts; expose roof of CHT; apply additional waterproof membrane (Fig 11).

(4) Construct ballast trough base (cast in three bays parallel to the direction of the arches to minimize the risk of unbalanced loading on them) (Fig 12). Construct tunnel base slab (this was cast on a 200mm minimum bed of sand, with a 30mm precamber). Construct tunnel walls and roof between piled foundations (Fig 13).

(5) Remove sand by flushing with a water jet; construct ballast trough walls; backfill to 0.0mPD.

(6) Fill ballast trough with water to the designed level; turn off the relief wells in the CHT; backfill to ground level and allow water table to recharge.

The project management challenge

The tunnel contract was very tightly programmed, with just over two years from contract commencement to track access, and team-building sessions were held between the KCRC, Arup resident site staff, and the contractor.

Despite the extreme risk of construction over the CHT, complex TTM, utilities diversions, ground movement, and water ingress control, the well-managed project team overcame all the challenges of this major civil engineering project in an extremely busy urban area adjacent to a harbour.

Conclusion

The alignment constraints and location made this one of Hong Kong's most challenging projects, with a timeframe from government public consultation to track access of only four years. During design development, major environmental impacts were minimized and objections carefully handled. The construction challenge of heavy civil engineering in an urban tourist environment with congested traffic and utilities, limited working space and access, sensitive structures and utilities, close proximity to the harbour, and the challenge of the CHT crossing, demanded a high calibre of engineering techniques and judgment.

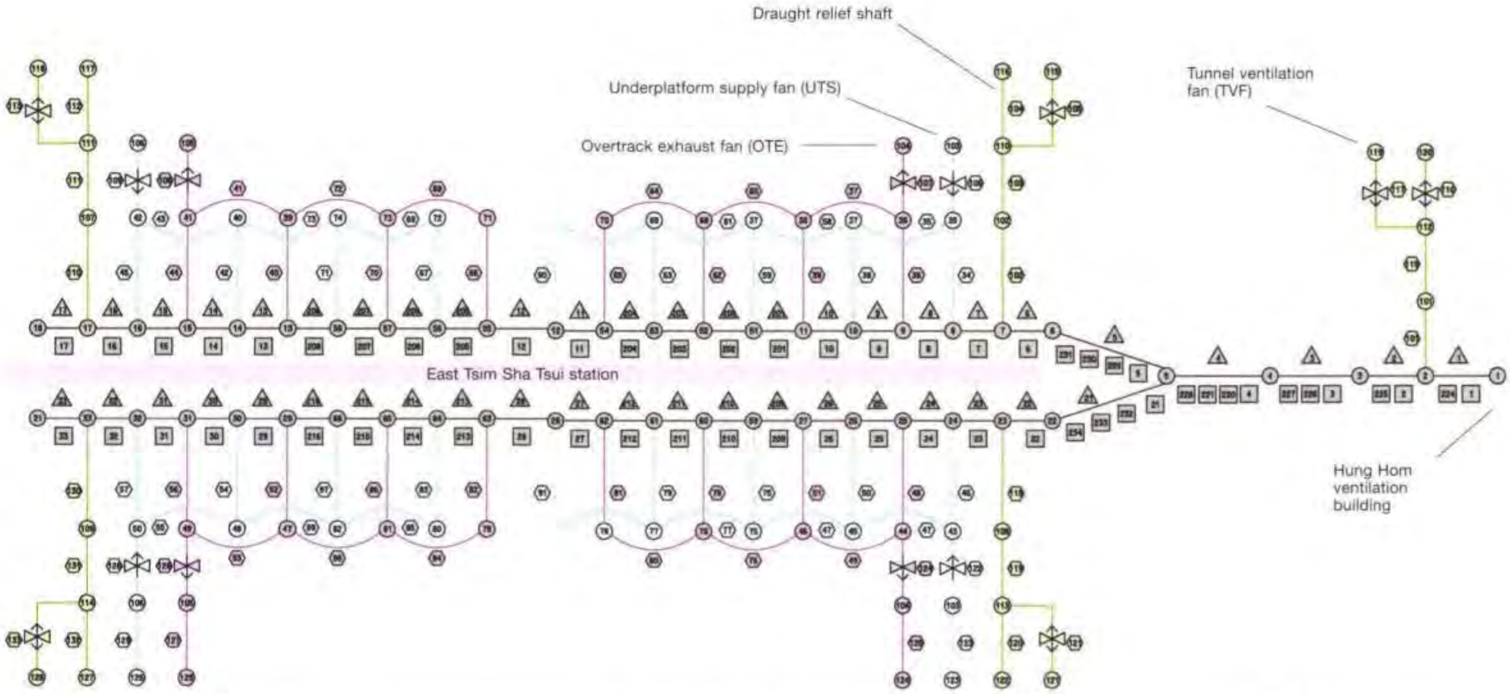
Teamwork between the KCRC, Arup, and the main contractor, Gammon Skanska, with a strong partnering spirit, positive attitude, and innovative ideas, was vital in overcoming many of the challenges. The key environmental impacts and social issues were minimized and addressed proactively, turning objections in public consultations to a win-win situation with hoteliers and building owners on their cooling mains.
All these factors contributed to achieving the key objectives: to be on time, within budget, and meet quality requirements safely.

Julian Hill, formerly an Associate of Arup in the Hong Kong office, was senior resident engineer for the HCC301 contract.

SS Kong, of Gammon Skanska Ltd, acted as project manager for the HCC301 contract.

Patrick Ng, formerly with the KCRC, acted as project engineer for the HCC301 contract, with particular emphasis on the liaison, public relations, and public consultation aspects.

This is an edited, updated, and expanded version of a paper by Julian Hill, SS Kong, and Patrick Ng that gained first prize in the Hong Kong Institution of Engineers Civil Engineering Paper of the Year Awards for 2003.



1. SES nodal schematic based on the tunnel geometry, alignment and design parameters. The deep sink temperature for this tunnel was taken as 28°C, the value being obtained from on-site monitoring tests. The temperature was slightly lower than normal underground soil in Hong Kong, as the tunnel is close to the sea.

Tunnel ventilation

Barry Lau Raymond Yau

Tunnel ventilation simulation tools

Subway environmental simulation (SES) is a modelling tool for numerically analyzing the aero-thermodynamic environment in subway transit networks.

It is a one-dimensional system that provides an overall view of airflow, temperature, and humidity under all modes of train operation, as well as cooling requirements for a tunnel.

Computational fluid dynamics (CFD) modelling is used for locations with a complex geometry, where airflow behaviour is complicated and likely to be three-dimensional. CFD enables the analysis of fluids in a 3-D domain, including heat transfer, mass transfer, and chemical reaction, by solving the mathematical equations that underly the physical process using a mesh-based iterative solution method. It can be used to simulate the air flow pattern and performance of a Saccardo nozzle*.

Introduction

The key factor in the tunnel ventilation system design was the need to contain the twin tracks in a single tube - rather unusual for a new underground system – and the absence of a central dividing wall influenced all aspects of the system design for normal, congested, and emergency operations.

Fundamentally, the system has to control smoke propagation and provide a smoke-free evacuation path during a fire emergency; remove heat generated by rail operation, so that the equipment's life expectancy is not diminished; and provide a suitable environment for passengers and maintenance personnel.

Special design considerations

Enlarged tunnel cross-section

Semi-transverse ventilation was not a feasible option as there was nowhere in the tunnel to accommodate air ducts, so a push-pull longitudinal system was designed for smoke control during fire emergencies, using fans at both ends of the tunnel to create airflow in one direction.

Due to the enlarged tunnel cross-section at the twin-track zone, the airflow from longitudinal ventilation had to be greater than for a single-track tunnel; both single-track and twin-track cases have to achieve the same critical velocity to control fire propagation and prevent smoke backlayering. Both SES and CFD analyses were conducted to ensure sufficient provision in the system.

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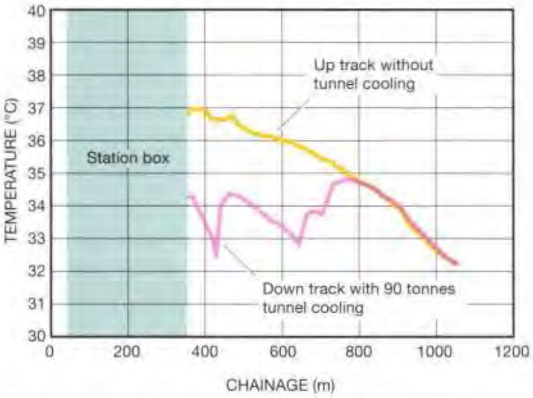
* In the Saccardo nozzle system, external ambient air is injected at high velocity into the tunnel at a shallow angle so as to generate air flow from the portal to the other end of the tunnel. Normally, most supply air from a fan system leaks to atmosphere rather than entering the tunnel, requiring an increase of fan capacity or ductwork extension inside the tunnel - both of which increase construction costs. The effectiveness of the Saccardo nozzle depends on its discharge velocity, the momentum exchange between the injected airflow and the surrounding air, and the injection angle, so performance simulation is needed to optimize the design.

Evacuation strategy in twin-track section

Safe passage for passenger evacuation and fire brigade access were two major concerns when designing the system. In a fire, the ventilation system activates and pushes smoke in one direction while passengers evacuate in the opposite direction. Depending on whether it is an external or internal train fire, passengers will exit through the train interior or on the evacuation walkway at the tunnel side. When all passengers reach the end of the train, operational staff lead them to a safe exit along the walkway.

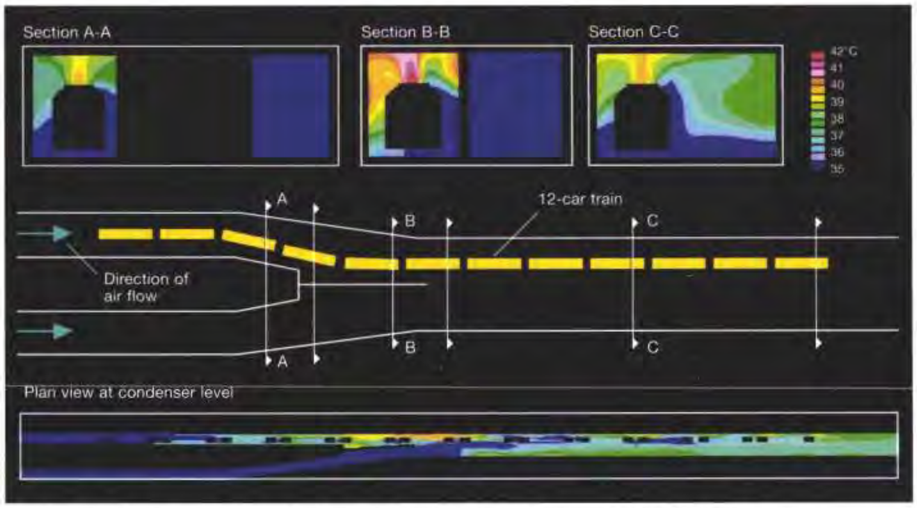
Tunnel cooling

Another major concern with the twin-track single-tube tunnel is the lack of piston effect under normal train operation, since airflow created by the trains running up track and down track cancels out. As a result, air circulation causes temperatures to increase significantly. SES analysis demonstrated that the temperature hotspot is at this twin-track section, and that the piston effect induced by train movement alone could not provide sufficient cooling to the tunnel air under normal operation.



2. Tunnel cooling comparisons: temperature profiles between East Tsim Sha Tsui station and Hung Hom ventilation building.

3. View of concrete air ducts supplying tunnel cooling to the twin-track tunnel.



4. Plan and sectional views showing the temperature profile around the train-borne air-condensers with a train at the twin-track tunnel section, under congested scenario.

Despite attempts to improve efficiency of heat removal by increasing mechanical ventilation of the trackway system and enlarging the size of draught relief shafts, tunnel cooling was still required for the approach section so as to meet the design temperature criteria (Fig 2).

A constant air volume system was adopted for tunnel cooling. East Tsim Sha Tsui station's centralized chilled water system feeds two air-handling units (AHUs) at the east end of the station, which distribute cool air towards the tunnel via concrete air ducts at high level along the dividing wall at the station end (Fig 3).

The supply air temperature of the cooling system is designed to minimize the possibility of condensation inside the tunnel. The cooling system normally operates on a timer system, but the tunnel air temperature is also monitored by linear heat detectors that can feed back to the station control room for optional manual control of the cooling system.

Train congestion

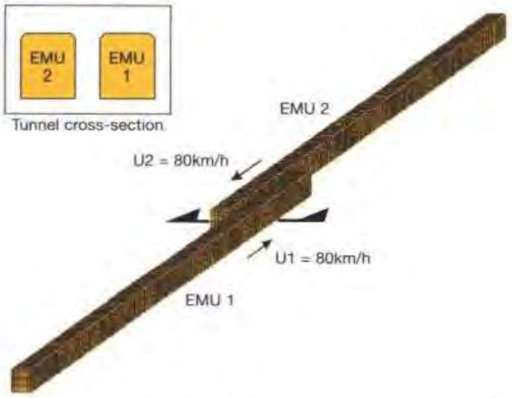
Under congested scenarios, tunnel ventilation fans create an airflow over the stationary trains, maintaining an appropriate quantity of fresh air for passengers, and removing heat from the trains' air-conditioning units.

To evaluate the temperature stratification when a train is inside the tunnel during congestion, SES and CFD analyses were employed to study the aerodynamic and thermodynamic situations. The former evaluated the airflow, and this simulated rate became the input condition of the CFD models, from which the temperature profiles around the air intakes of the train-mounted air-conditioning unit condensers in the tunnel were estimated.

Fig 4 shows a train at rest in the twin-track section, and the temperature profile surrounding the train-mounted air-condensers. A dividing wall separating the up track and down track alters the supply airflow rates from the station trackway, due to airflow blockage by the train. Beyond the station box, at the twin-track single-tube section, the airflow was distorted and temperature fluctuated, but nonetheless the design criterion (46°C) at the air intake location of condensers could still be maintained for the specific congested scenario.

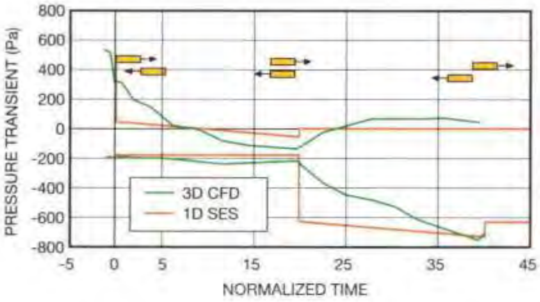
Tunnel aerodynamics

A major concern with operation in a twin-track single-tube tunnel is the fast passage of two trains in opposite directions, where significant aerodynamic forces can cause aural discomfort to passengers and potentially affect safe operation. CFD modelling was used to evaluate the pressure transients (Fig 5), and the results compared with a one-dimensional SES analysis (Fig 6).



5. CFD computational grid of trains and tunnel cross-section at twin-track single-tube section.

6. Recorded pressure transients at train noses and tails.



Pressure transients of the entire train passage were simulated, and the history of near-field pressures at the train nose and tail recorded. The 3-D CFD model indicated a continuous and steep change in nose pressure as the two noses met, but a moderate change in tail pressure when one train nose met the other's tail.

When compared with the results generated by SES, a discontinuous change throughout the process was found, which may be attributable to the three-dimensional airflow around the train noses and tails. Nonetheless, the magnitude of pressure changes simulated by the two models matched. In addition, the rate of change of pressure did not exceed the design criteria for aural comfort.

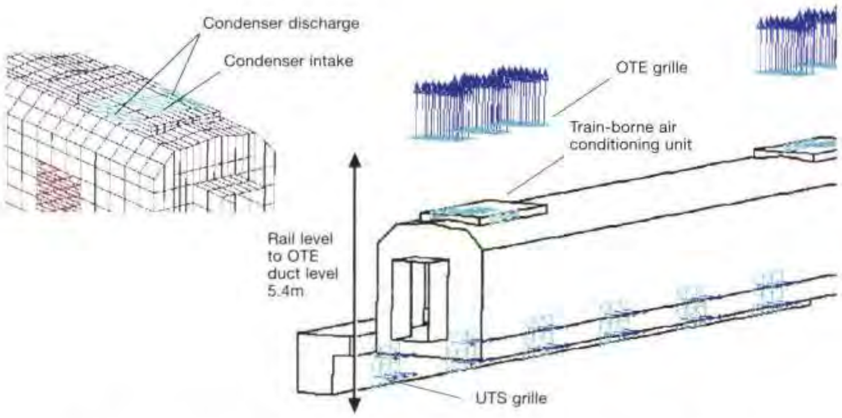
Significant pressure change at the front of the train (Pn+) was found when two train noses met (Fig 6), with pressure decreasing in both models. As the train nose met the tail of the other train, Pn+ started to recover, but the rate of pressure change was much slower. At the train tails, pressure change occurred when the train nose passed the tail of the other train, with pressure at the tail (Pt-) decreasing steadily but much more slowly than the change in Pn+. Pt- then recovered when both train tails passed each other.

Trackway ventilation at East Tsim Sha Tsui station

At the station, the trackway ventilation system consists of under track supply (UTS) and over track exhaust (OTE), with operating capacities of $64m^3/s$ and $52m^3/s$ respectively. These operate continuously under normal, congested, and incident scenarios for the station ventilation system. However, under emergency operation, if a fire occurs between two stations, both UTS and OTE close to minimize the risk of short-circuiting with the tunnel ventilation fans. If, on the other hand, a fire occurs at the station trackside, OTE operates to extract smoke within the trackway.

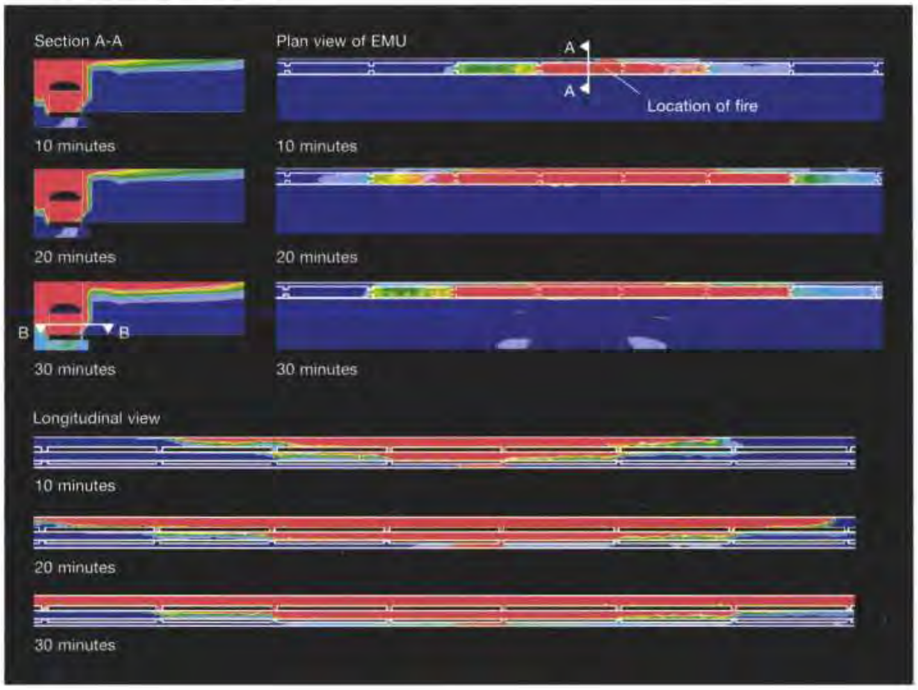
Effect of trackway ventilation capacity on tunnel air temperature

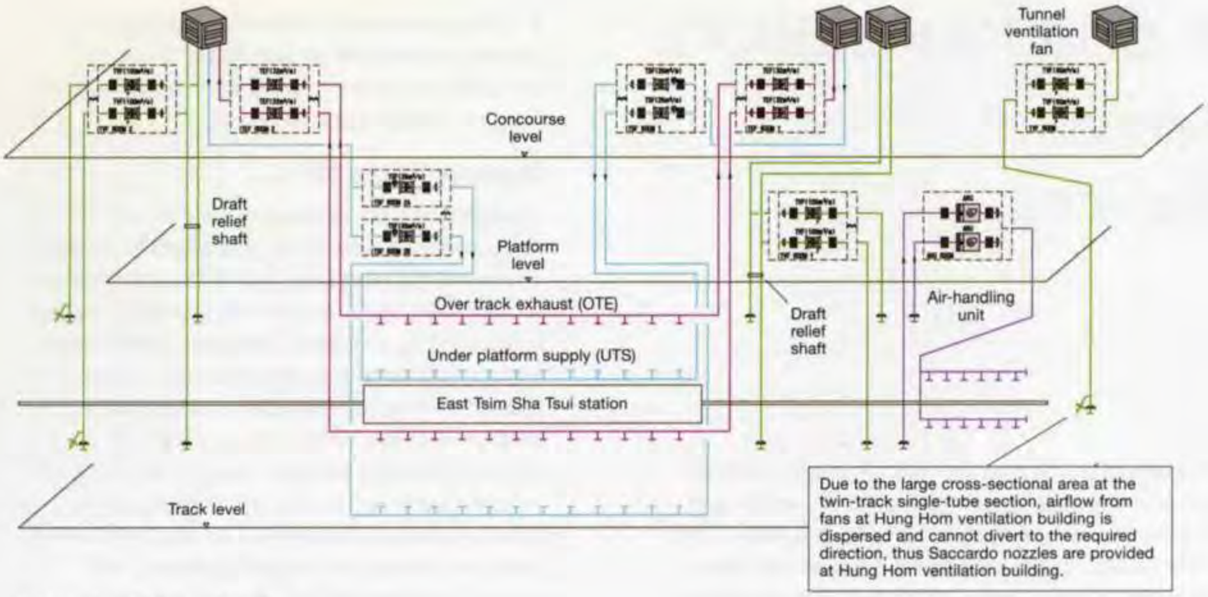
To lower the tunnel air temperature, and thus reduce the amount of tunnel cooling needed, CFD analyses were carried out to investigate the effect of increasing fan capacity of both OTE and UTS at the station. However, the study showed that this would only minimally reduce the tunnel air temperature at the twin-track tunnel section, and the same amount of tunnel cooling would still be required.



7. CFD model demonstrating train car geometry and boundaries at East Tsim Sha Tsui station.

8. Longitudinal and sectional views demonstrating the smoke dispersion of an external train fire at East Tsim Sha Tsui station.





Due to the large cross-sectional area at the twin-track single-tube section, airflow from fans at Hung Hom ventilation building is dispersed and cannot divert to the required direction, thus Saccardo nozzles are provided at Hung Hom ventilation building.

9. Tunnel ventilation schematic.

10. Tunnel ventilation fan in station.

11. Tunnel cooling air-handling unit in station.

Infiltration and exfiltration through platform screen doors (PSDs)

As well as the tunnel ventilation system, the trackway ventilation also has to interact with the station's environmental controls.

When a train is at rest in the station with PSDs open, infiltration (airflow from station to tunnel) or exfiltration (airflow from tunnel to station) via PSD openings would occur due to thermal driven airflow and/or pressure generated by the UTS and OTE systems. If exfiltration through PSDs was greater than infiltration, hot air driven from tunnel to station would cause thermal discomfort to passengers.

As a result, the trackway ventilation system had to be optimized with appropriate make-up air from the UTS system, and CFD models were used to study the thermal geometry between the tunnel and station environments (Fig 7). These showed that provision of 80% make-up air from the UTS system has the least exfiltration, thus offering the lowest additional load to the environmental control system.

Station fire

Apart from normal ventilation provisions, the trackway ventilation system is also required to operate during a station fire (Fig 8).

CFD modelling was used to investigate the details of smoke spread under the operation of the trackway ventilation system.

Testing and commissioning

Having progressed the design from overall schematic (Fig 9) to finished project (Figs 10-14), the final major hurdle for the tunnel ventilation design was to test and commission the systems individually and together.

The biggest challenge was the fire inspection testing of the twin-track tunnel, a key measure of the reliability and safety of the ventilation system. This is particularly important for fire scenarios at the twin-track single-tube section, due to the large cross-sectional area where a significantly large airflow is needed to control smoke direction and prevent smoke backlayering.

The new Hung Hom ventilation building is directly over the twin-track tunnel at the portal, very close to Hung Hom station podium, so there was a chance that not all the smoke could be exhausted through the ventilation building; some might spill into Hung Hom station and affect its normal operation. A cold smoke test was thus performed at the twin-track tunnel section to evaluate smoke dispersion with the tunnel ventilation system operating. This was successful, with no smoke spilling into Hung Hom station (Figs 12-14).

Raymond Yau is a Director of Arup and the head of the Building Physics Group in the Hong Kong office. He was the tunnel ventilation team leader for the design of the trackway and tunnel ventilation systems of the underground tunnels between East Tsim Sha Tsui and Hung Hom stations.

Barry Lau is an Associate of Arup in Hong Kong and was the project tunnel ventilation engineer.

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12. Initial release of cold smoke for twin-track tunnel test.

13. Tunnel ventilation system pushing smoke towards Hung Hom ventilation building.

14. Smoke extracted before it can enter Hung Hom station.

East Tsim Sha Tsui station:

design challenge to building services

Clement Chung

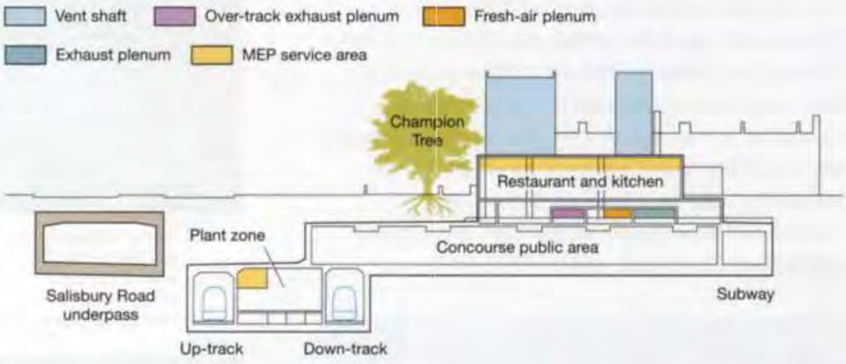
Introduction

The Salisbury Road alignment severely constrained the station's position, which in turn posed many challenges to planning and designing the building services and their systems. All disciplines (architect, landscape architect, building services, civil, structural, tunnel ventilation, and utilities) had to be integrated to make the plant and equipment fit and work in limited spaces – much of the plant and ventilation air plenums were built in irregularly-shaped rooms, due to the plan configuration of the station box.

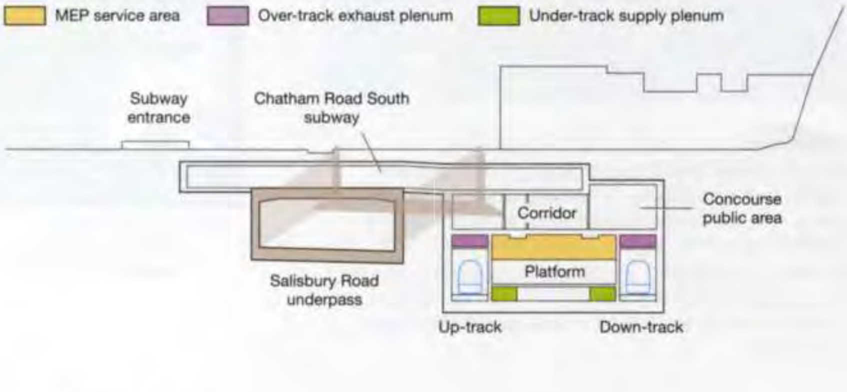
Fixed utility constraints

Due to the severe planning constraints at ground level, two electrical substations supplying power to the station were sited alongside two large-scale arrays of fibre optic telephone cables that could not be diverted. Substation walls were thus oriented so that the cables passed through them.

1. Cross-section showing relationship between Champion Tree, station box, and Salisbury Road underpass.



2. Cross-section showing relationship between station box, Salisbury Road underpass, and Chatham Road South pedestrian subway.



A 1.2m diameter sewer that also could not be diverted required special planning of the tunnel ventilation fan rooms to integrate it into a structural trough in the fan room ceiling.

Champion Tree no 251

The tree (see p12) stands above the air-conditioning plant, overtrack exhaust air, and undertrack supply air plant at the concourse back-of-house zone, and so effectively blocks air plenums at ceiling level. To overcome this, a series of additional walls forming fresh air and exhaust air plenums were planned and routed to link up with the plant and ventilation shafts, more than 100m from each other (Fig 1). The required static pressure was carefully calculated for sizing each fan to cope with this long run for different operational scenarios, so as to ensure that fresh and makeup air can be supplied to, and smoke air exhausted from, the platform and concourse zones.

Salisbury Road underpass and Chatham Road South pedestrian subway

Another challenge was to construct a new four-lane highway underpass and reprovision the previous pedestrian subway that was demolished to make way for the new station. The approach ramp sections of the underpass are adjacent to and overlay the station structure, forming the irregularly-shaped spaces into which the plant and ventilation air plenums had to fit, as noted above. Also, the new subway was integrated with the concourse roof slab to provide the minimum KCRC requirement for 3m ceiling height in the concourse (Fig 2).

3. Exhaust-air vent shaft integrated with passenger lift.

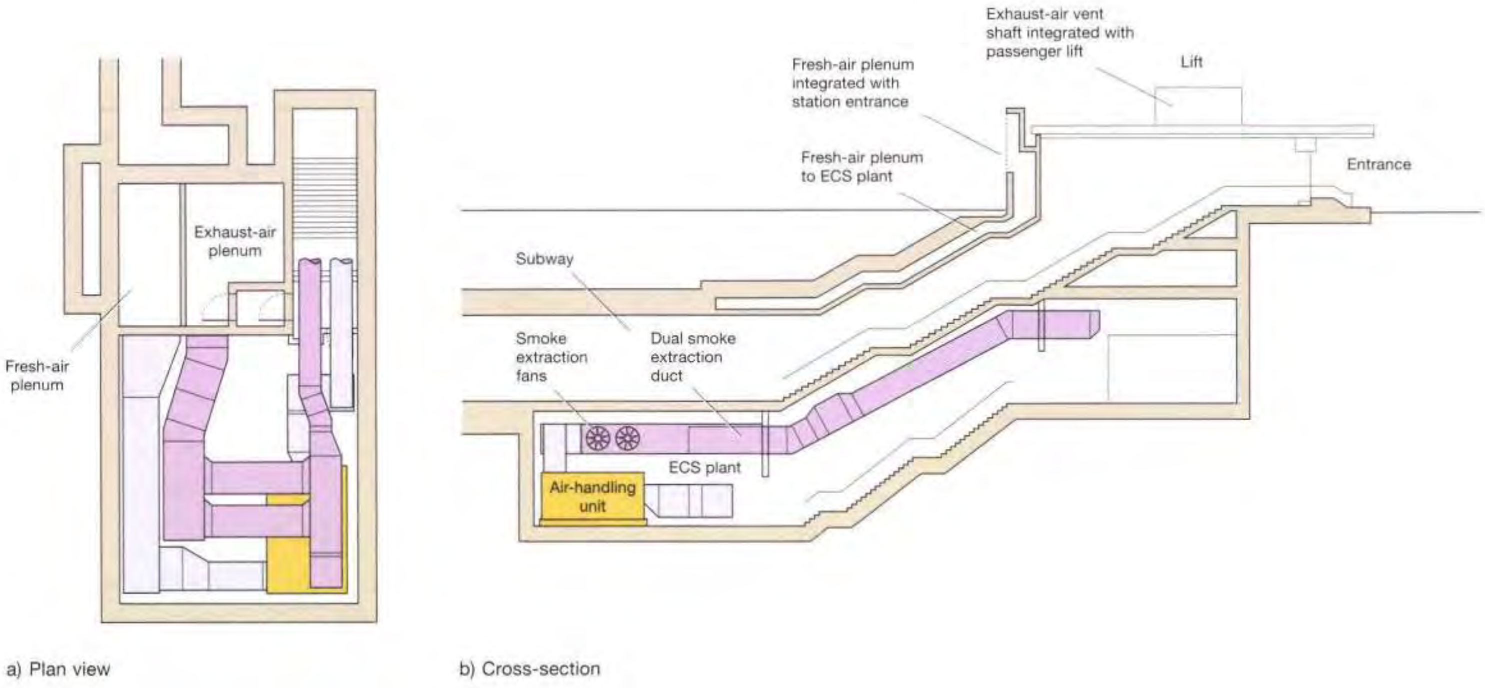
Firefighting rescue staircases

Statutory regulations require two emergency access points to run directly from street to platform level at each end of the station, but due to the location beneath Salisbury Road, this could not be achieved. To overcome this, stairs and lifts were split horizontally so that platform-to-concourse and concourse-to-ground are separate entities linked by relatively long, fire-protected corridors. Designing the staircase pressurization system to *BS5588*[1] was another challenge.

Mody Road pedestrian subway

This 400m long subway connects East Tsim Sha Tsui station with the MTR Corporation's Tsim Sha Tsui station on the Tsuen Wan line. It was designed with air-conditioning and smoke exhaust systems, but the location beneath Mody Road gave no plant space to accommodate equipment. Furthermore, statutory regulations required the fresh air intake to be a minimum of 5m from any smoke discharge outlet. This imposed another constraint on planning the fresh air intake and smoke exhaust ventilation shaft, which was solved by putting the plant right at the entrance, underneath the pedestrian level. The fresh air intake louvre was integrated with the subway entrance so that air was supplied from there to the plant through a connecting concrete air duct. Smoke is exhausted from a freestanding shaft distant from the entrance to provide the required separation (Figs 3-5).

5. One of the subway entrances.



a) Plan view

b) Cross-section

4. Air-conditioning and smoke exhaust air plant underneath subway entrance.

System design

With the objectives of cost-effectiveness, improved reliability, and reduced interference, the Arup team's aim from the outset of the commission was to achieve:

- reduction of capital cost (for civil engineering and architecture as well as for building services)
- reduction of building services operating costs in terms of energy efficiency and cost-effectiveness
- reduction of design programme and construction duration
- improved durability, maintainability, and accessibility of the services systems.

These were designed to meet the functional and operational requirements of the KCRC's standards, and Arup's design methodology adopted the following approaches to achieve the goals:

- Maximize the systems' maintainability, eg standardize equipment sizing.
- Maximize the use of ceiling void spaces for services passing through the front-of-house (ie station operation rooms) and railway systems equipment rooms from the building services plant. The team successfully demonstrated that, by introducing an intermediate slab as a kind of structural ceiling above the station operation rooms and railway systems equipment rooms, the required co-ordination works between trades for structure and services elements could be significantly reduced. Wall penetrations were minimized, compared with full-height walls that run slab to slab, and electromagnetic interference between building services equipment and sensitive railway system electronics was eliminated by the separating slab.
- Minimize the interface works between disciplines. For instance, wherever possible a permanent fixed smoke barrier was installed above the ceiling, instead of automatic drop type smoke curtains to segregate smoke control zones. This avoided maintenance costs for these curtains.
- Locate building services equipment outside the railway systems equipment and station operation rooms to minimize electromagnetic interference.
- Make water pipes run outside the railway equipment and station operation rooms, to avoid water damage from leaks.
- Provide standby facilities to serve the railway systems equipment and station operation rooms, and separate routing for main cables to improve reliability.

6. Water-cooled centrifugal chiller in main station plantroom.

7. Plate heat exchanger and pipework from seawater pumping station in main station plantroom.

Smoke management system

The station operation forbade physical compartment walls in the concourse, platform, and public areas, so the smoke control systems design followed a fire engineering approach to achieve cost effectiveness without compromising safety requirements. Smoke compartmentation or a smoke zoning system with necessary smoke barriers was provided to form a smoke reservoir, the area of which could vary but was not to exceed 2000m^2. Arup's fire and smoke management objectives were to:

- limit the smoke spread from a fire
- dilute the smoke within the space with fresh air to maintain tenability and improve visibility
- provide a smoke-clear safe environment on escape routes
- manage the smoke radiation rate to avoid skin burn to evacuees
- limit the length of travel under a smoke layer
- control fire spread from the station trading areas
- ensure the reliability of smoke extraction equipment to withstand lengthy and hot exposure to fire.

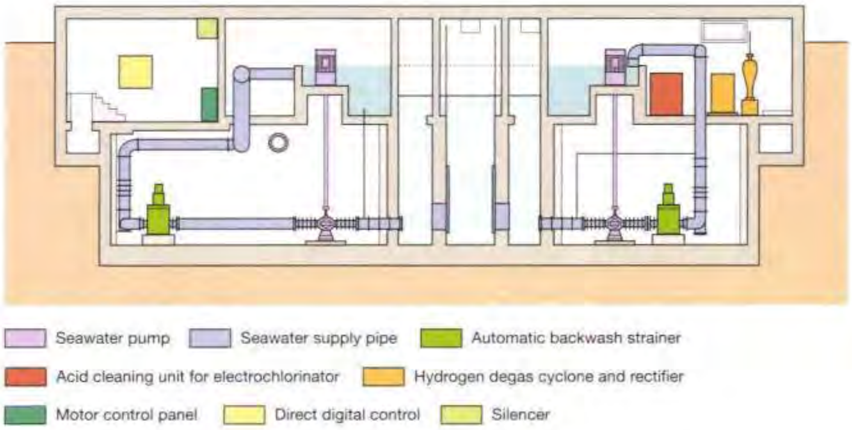
The base of the smoke layer is usually set above head height (minimum 2.1m above the floor), but here it needed to be higher, because the downward intensity of radiation was not to exceed 2.5kW/m^2. This corresponds to a limiting smoke layer temperature of 180°C. This approach was used to determine the smoke clear height and has now become the basis for review of the design of future station projects by the Hong Kong Fire Services Department. Arup's design achieved:

- a smoke reservoir/zone for the public areas not greater than 2000m^2
- a smoke-clear height at 2.5m or above
- downward radiation intensity exposure from smoke layer $<$2.5kW/m^2
- smoke extraction equipment suitable for continuous operation at 250°C for not less than one hour.

Use of seawater cooling system

As ground-level space above the station was at a premium, no reduction in area of the reprovisioned elevated landscape deck was possible, making the location and space provision for station cooling plant a critical issue. Space could be saved by using seawater cooling instead of an air-cooled system, and this was helped by the station's proximity to the harbour, but the cooling demand for the station and subway is only 5500kW (1560 refrigeration tonnes). Cost analysis showed the capitalized cost and total present cost of the seawater-cooled chiller option over a 25-year lifecycle to be higher than that of the air-cooled option. The low return

8. East Tsim Sha Tsui promenade, showing the running tunnel site with (a) intake pipes, (b) outfall pipes and (c) the new seawater pumping station.



9. Seawater pumping station long-section.

value of energy saving was also insufficient to pay off the additional capital investment cost of building a seawater pumping station. Nonetheless, the seawater-cooled chiller option prevailed, as it offered several important advantages:

- Unlike the original KCRC technical study there was no need to cut away Signal Hill to accommodate plant.
- Avoiding Signal Hill secured government approvals more readily and was environmentally much more acceptable.
- Less plant space was needed than the air-cooled chiller option, giving better flexibility for station planning (Figs 6, 7).

As already outlined on pp13-14, circumstances supplied a site for a new seawater pumping station immediately adjacent to the station approach tunnel on the harbour promenade (Fig 8), with the abandonment by the nearby Hong Kong Polytechnic University campus of its existing seawater system and relinquishing the site for a new pumping station structure (Fig 9).

Co-ordination with railway systems contracts during construction

The civil contract for the station (HCC300) interfaced with 11 railway systems contracts: (1) escalators; (2) lifts; (3) train control and signalling; (4) traction power and overhead line; (5) telecommunication; (6) commercial communication; (7) integrated communication and control system; (8) automatic revenue collection; (9) platform screen doors; (10) permanent way; and (11) station signs and advertising panels. All were either supply-and-install or design-and-build contracts. Although, strictly speaking, a railway systems contract, the tunnel ventilation system was included in HCC-300 even though it was physically installed in a large ventilation building directly above the adjoining running tunnel in civil contract HCC301.

The railway system's requirements had to be well understood and fully incorporated into the tender package. For ease of monitoring and supervision, Arup developed interface schedules and schematic diagrams, in compliance with the KCRC's interface specification and design criteria, to specify the design provisions and identify interfaces between the three civil contracts and the railway system's contracts. These schedules and schematics were also then used on site in discussions with the railway systems contractors through the interface management plan and detailed interface document stages, and were updated as necessary. These ensured the railway systems requirements were fully incorporated with nothing omitted.

When each civil contractor prepared his structural/ electrical/mechanical (SEM) drawings showing all cast-in items and openings, and his combined services drawings (CSD) for construction, Arup required him to convene a workshop with all the railway systems contractors to ensure that their concerns and requirements had been discussed and included in the SEM and CSD. When all was agreed, the drawings were signed and submitted to the resident site staff team for review. Arup chaired meetings to consolidate the KCRC's railway system engineers' comments and to check the SEM for structural integrity and the CSD for services maintainability. For ease of checking, any new opening, relocation, or deletion from the SEM drawings was also identified and the exercise repeated until all comments were fully incorporated. This attention to detail, with checks and counter-checks, resulted in a highly integrated product, with no major omissions in the structural works.

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MOS Rail system-wide fire safety strategy:
approach and justification

Mingchun Luo Kelvin Wong

1. Concourse on MOS Rail's Heng On station.

Introduction

The complexity and size of railway projects mean that standard fire safety regulations cannot always be applied. Having developed comprehensive experience and capability at the forefront of fire safety engineering, Arup was appointed to justify the fire engineering issues on all nine of the Ma On Shan (MOS) Rail stations (Tai Wai, Che Kung Temple, Sha Tin Wai, City One, Shek Mun, Tai Shui Hang, Heng On, Ma On Shan, and Wu Kai Sha) that did not conform with existing regulations and the conventional practice on fire safety matters common for commercial buildings. A performance-based concept was adopted and developed to optimize the design outcome and cost.

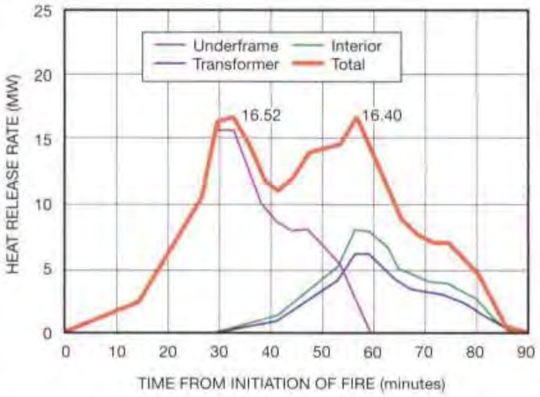
After submission of the fire safety strategy report for MOS Rail stations to the Government committee for safety and security, Arup was asked to give detailed justifications for several technical issues including fire sizes, compartmentation, omission of sprinkler protection to station public areas, use of escalators for evacuation, station population calculations in evacuation modelling, maximum evacuation time of 4.5 minutes, use of the "cabin" concept for station trading areas and maximum allowed evacuation distances in stations.

Fire sizes

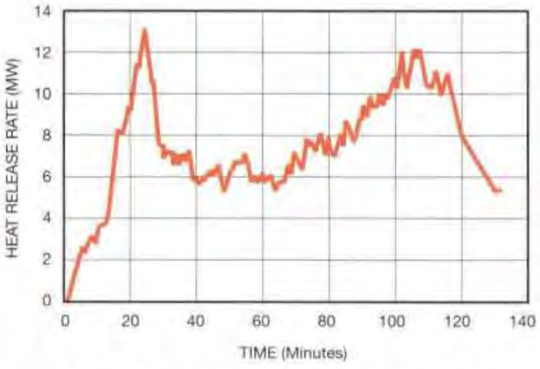
Design fire size forms the basis of fire engineering analysis. Fire size dictates smoke production rate, which in turn determines the required capacity for the smoke extraction system. The design fire is also used to estimate the time available for safe passenger evacuation. For MOS Rail, several studies for the design fires were performed, based on international peer-reviewed literature[1], real fire test data[2], and computational calculations.

Comparing fire test data gives a much lower peak heat release rate for train fire and baggage fire, and the adopted design fire sizes in the fire safety strategy report were considered to be conservative and highly reliable. A large safety margin was implemented in the fire safety system design: compare the design fire curve for MOS Rail (Fig 2) and the full-scale fire test result of a German train carriage (Fig 3).

If fast-response sprinkler heads are installed in the retail areas inside stations, the design fire size can be reduced by half compared with the original value recommended in the 1980s for shops protected by standard-response sprinklers. Reducing the design fire size can also optimize retail area smoke extraction system design, such as fan and duct sizes.



2. Heat release rate of MOS Rail train car derived from the total heat load.



3. Heat release rate from a full-scale test of a German passenger train carriage.

Compartmentation

Station functional requirements made it impossible to divide the station area into fire compartment volumes of the 28 000m^3 maximum stipulated in Hong Kong's prescriptive code[3]. However, justifications based on station design, fire spread calculations, and occupant characteristics showed that compartmentation is inappropriate for a station public area.

Arup experience and current railway practice showed that the most efficient way to evacuate stations is to utilize normal access routes that allow clarity and ease of passenger flow. It is thus neither practical nor desirable to fully compartmentalize these public areas being used as an escape route.

In the smoke and fire spread analysis, the team considered it unnecessary to limit the compartment size to 28 000m^3, as fire and smoke in the station trading areas would be relatively small, and thus would not spread to adjacent areas. With the adoption of the "cabin" concept[4] for the relatively high fire risk station trading area, fire hazard could be well controlled.

Omission of sprinkler protection to station public areas

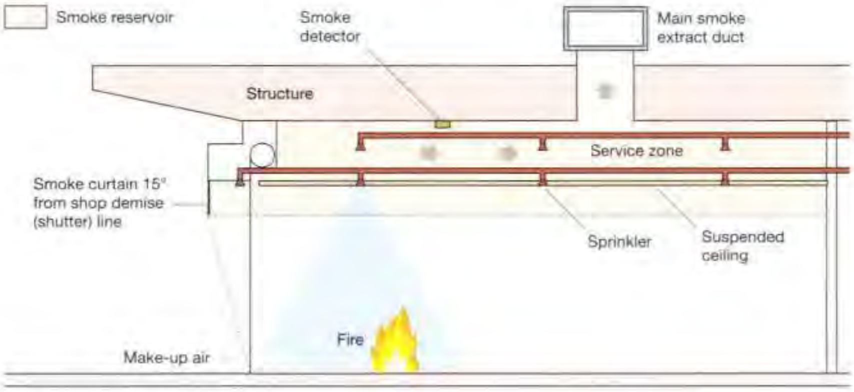
Most of the station public areas, eg trackway, platforms, concourse, passageways, and staircases, have no sprinkler protection. The same principle as for other Hong Kong stations was used to justify this. In public circulation areas, all surface finishes are non-combustible materials, which means a very low fire load and thus the likelihood of only a small fire. Also, in concourse and platform areas any sprinklers are unlikely to be activated due to the small size of a baggage fire and the high mounting position of the sprinkler heads.

Finally, activating sprinklers in public areas can cause passengers to slip, potentially (and dangerously) impeding evacuation. For most of the station public areas, sprinklers were, therefore, an unnecessary provision.

Use of escalators for evacuation

Station emergency evacuation procedures are developed to ensure that evacuation is timely and all facilities are in proper operating modes. It was proposed that escalators running in the evacuation direction from a fire should continue to operate, whilst those running counter to it should be halted and used as stairs to aid evacuation.

International practice and guidance[5] do allow escalators to be used as means of egress, but in this instance statistically reliable data, fire safety provisions, and escalator specifications were also studied to justify that international practice would be suitable for Hong Kong.



4. Schematic of cabin concept.

As for the behaviour of people, several studies[6, 7] showed that passengers tend to use familiar routes, particularly in an emergency. Given the high reliability of escalators due to regular inspection and maintenance, their use in principle as an escape route was allowed. However, as a fail-safe measure, one of the escalators was discounted as a means of escape whilst stairs continued to be provided to fulfil this function, in combination with the escalators.

Station population calculations and evacuation time

The total station population load is estimated from the traffic parameters instead of the station area. The calculation includes the "crush train load" - the maximum number of people that can be accommodated in a train - plus the "peak boarding load", which is derived from statistical data. With the consideration of additional passengers due to a missed train, a conservative and reasonable population can be estimated for evacuation modelling.

The maximum travel distance in station areas exceeds those specified in the Hong Kong prescriptive code. However, in the station design, the team made smoke calculations which demonstrated that egress would be safe for longer than 30 minutes with the smoke layer above occupants' head height and so not affecting them. The critical evacuation time of 4.5 minutes from the incident zone was specified to ensure that passengers could evacuate reasonably quickly and still avoid crowd crushing. With the emergency announcement using an automatic voice system to initiate evacuation, supplemented by flashing exit signs, rapid evacuation guidance with a significant safety margin was provided for the 4.5 minutes evacuation time.

Use of "cabin" concept for station trading areas

The "cabin" concept was first proposed by Arup's Margaret Law[8] as a way to prevent spread of fire and smoke in high fire load areas without using fixed or movable fire-rated building elements such as fire walls or fire shutters. Fire safety systems inside the "cabin", including sprinklers, smoke detectors, smoke extraction systems and smoke barriers, protect people and property. Should a fire occur, its size will be controlled by sprinklers and the smoke will be extracted, so there will be no spread of fire and smoke from the cabin to its adjacent area (Figs 4, 5).

The "cabin" concept has been used in some significant Arup-engineered transport buildings around the world, including Hong Kong International Airport[9], Japan's Kansai International Airport[10], the UK's Stansted Airport[11], Beijing International Airport Terminal 3, and various rail stations in Hong Kong. From historical data, and full-scale fire tests conducted at the Hong Kong Fire Services Department Training School (Fig 6), the effectiveness of the concept has been well proven. Together with the prohibition of dangerous and highly flammable goods, the "cabin" concept is used to protect the MOS Rail station trading areas.

Maximum travel and deadend distance

The maximum travel distance and deadend distance in the MOS Rail stations do not comply with the prescriptive code[12] values. Since the prescriptive code sets no requirement for the deadend distance in transport-related facilities, the team adopted a fire engineering approach based on station characteristics.

With a fire engineering approach based on evacuation time rather than travel distance, evacuation from the incident area can take less than 4.5 minutes. International codes[13] allow a similar maximum travel distance for residential or commercial buildings and much longer maximum travel distance for special purpose buildings, eg transport terminals. With constantly monitored station public areas and well-established evacuation procedures, an efficient station evacuation scenario can be maintained.

Summary

A fire prevention strategy was also established for each MOS Rail station, including inspecting and maintaining fire services installations, housekeeping procedures to remove fire hazards, limiting the introduction of combustible materials, security and vigilance by staff to limit risks of deliberate fires, and staff training for fire drills, incident handling skills, first aid fire fighting, and emergency communication and evacuation procedures. Further education of the public to increase awareness of fire hazards, the risk of deliberate ignition, how to quickly report a fire and what to do in the event of one, was done through safety campaigns as part of the comprehensive fire prevention strategy. With holistic fire engineering analyses from a performance-based approach, the above fire safety issues on the design of MOS Rail were addressed and justified, thus reducing the fire risk and enhancing public safety in day-to-day uninterrupted railway operation.

5. Trading areas on the MOS Rail station concourses use the "cabin" concept to ensure fire safety.

6. Cabin concept full-scale fire test.

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The Kowloon Southern Link feasibility study

Timothy Suen Colin Wade

Introduction

The concept of linking the KCRC's West Rail system[1] with its original East Rail line via the Kowloon Peninsula was first noted in the Hong Kong Government's railway development strategy published in 1994. The KCRC undertook preliminary studies between 1997-1998 as part of its proposed East Rail extensions projects, but at that time the link was indicated as depending on the construction of a large reclamation in Victoria Harbour to be known as Kowloon Point, immediately to the west of the southern tip of Kowloon Peninsula.

Since then, the Hong Kong government has put an embargo on harbour reclamation unless there is no viable alternative. In the case of the Kowloon Southern Link (KSL), there clearly were alternative railway alignments, and in 2000 the KCRC called for consultancy bids for a preliminary feasibility study to confirm that the project was still viable without Kowloon Point reclamation. Arup won the commission and the seven-month study commenced in January 2001.

1. Aerial overview from Victoria Harbour with the KSL route superimposed: (a) Nam Cheong station and overrun tunnels (West Rail), (b) MTR Airport Express and Tung Chung lines, (c) West Kowloon station, (d) Harbour City complex, (e) Canton Road, (f) Ocean Terminal, (g) Star House, (h) Star Ferry terminal, (i) former Marine Police headquarters, (j) original KCRC terminus clocktower, (k) former fire station, (l) Hong Kong Cultural Centre, (m) YMCA building, (n) Peninsula Hotel, (o) Space Museum, (p) MTR Tsuen Wan line, (q) Salisbury Road, (r) East Tsim Sha Tsui station and overrun tunnels, (s) Sheraton Hotel, (t) Kowloon Park Drive, (u) Nathan Road, (v) MTR Kwun Tong line, (w) MTR Olympic station.

2. Overview of Kowloon Southern Link.

The route

The KSL is a 3.75km, wholly underground, twin-track railway. The line will run from the overrun tunnels west of the current East Rail terminus at East Tsim Sha Tsui to the overrun tunnels south of the current West Rail terminus at Nam Cheong in the Sham Shui Po district (Fig 2).

Urban context

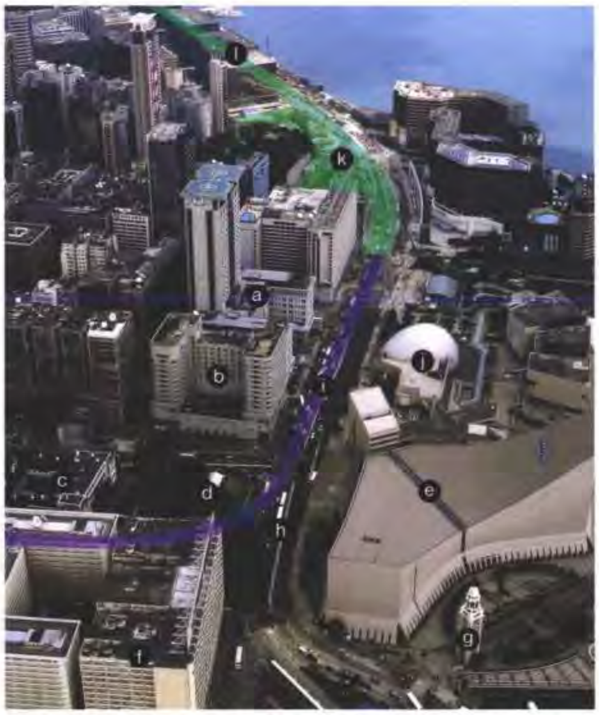
The railway runs through two distinct areas. The south section is a very dense, highly-developed, urban environment (Fig 1), whilst the north is less developed, being fairly newly reclaimed land.

South section:
East Tsim Sha Tsui station to Jordan Road

Running beneath the urban fabric of the Kowloon Peninsula in the tourist and shopping district of Tsim Sha Tsui, this area is characterized by a heavily trafficked road network with a dense mix of building types and uses - mainly hotel, commercial, and retail, but some residential blocks. Buildings range from new to listed historical structures.

West of East Tsim Sha Tsui station, the tunnels are aligned beneath Salisbury Road directly across the twin-tube running tunnels of the MTR Tsuen Wan Line and close to the prestigious Peninsula Hotel (Fig 3), the Hong Kong Cultural Centre with its arts and theatre venues, as well as the Space Museum (Fig 4). Turning north with very tight radii of 225 and 240m, the twin tunnels pass directly under two small listed brick buildings that housed the former Tsim Sha Tsui fire station, and a remaining hillock of land on which stands the former Marine Police headquarters – also listed.

3. Nathan Road crossing, envisaged as an in situ box to accommodate a possible integrated basement car park for the hotel: (a) Peninsula Hotel, (b) Nathan Road, (c) Salisbury Road, (d) KSL tunnels, (e) MTR Tsuen Wan line.



4. Salisbury Road alignment into Canton Road: (a) Peninsula Hotel, (b) YMCA building, (c) former Marine Police HQ, (d) former fire station, (e) Hong Kong Cultural Centre, (f) Star House (Canton Road behind), (g) original KCRC terminus clocktower, (h) Salisbury Road, (i) KSL tunnels, (j) Space Museum, (k) East Tsim Sha Tsui station and overrun tunnels, (l) running tunnel to Hung Hom station.

The alignment continues north beneath Canton Road, close to and partly under an elevated road at the junction with Kowloon Park Drive, and then skews north-west into the site allocated for West Kowloon station.

North section: Jordan Road to Prince Edward roundabout

After leaving West Kowloon station, the alignment runs northwards. This section is wholly within reclamation laid down in the early/mid-1990s as part of the land required for the highway and railway corridor created for Hong Kong's new airport at Chek Lap Kok. Much of this marine sand reclamation was carried out in various contracts and numerous phases to allow the transport corridor to be constructed for the airport, which opened in 1998[2]. Areas at the southern extremity, and not part of the airport project works, have been completed more recently. This northern section of the route is constrained by the new highway infrastructure and the MTR Airport Express and Tung Chung lines (formerly the Lantau and Airport Railway, or LAR), which is partly in tunnel and partly at-grade in this section.

The KSL will run very close and parallel to the MTR Olympic station in the Tai Kok Tsui district, and underpinning of some station access footbridge piers was identified in the study. Here the tunnels also pass immediately below a large road underpass at Cherry Street and a group of four twin-cell box culverts also requiring a large-scale sequenced underpinning exercise. New high-rise developments associated with the LAR are also now in place around Olympic station, with some land areas still awaiting development for use as public open spaces and other future amenity projects.

Potential stations

At the time of the study two new stations were under consideration. Due to the siting of the LAR Kowloon station, it was logical to place a new KSL station as near as possible to it, with potential passenger links between the two. Thus a station currently named West Kowloon was allocated on an area of land already reserved for a much larger cross-boundary and domestic KCRC station studied by Arup in 1996. A second station further south in the Tsim Sha Tsui district looked promising as its logical location placed it in the heart of the tourist, hotel, and shopping area near Ocean Terminal, the busy cruise liner facility containing many shops and restaurants. It was also immediately adjacent to Harbour City, another large-scale shopping, hotel, office, and apartment complex fronting Canton Road (Fig 2). All was therefore set to provide a station to be named Canton Road.

Study requirements

The purpose of the study was to confirm that it would be technically possible to build the KSL having due regard to environmental matters and other issues such as constructability, land ownership, heritage structures, traffic, access, effects on business, demolition, underpinning, and building resumption. Cost and programme were to be assessed, and potential for property development to be investigated at the two possible station locations. At the end of the study a formal project proposal was to be compiled for submission to the Hong Kong government. This would allow the necessary procedures to be put in place to gain formal approval for the project, enabling the next stage of design and construction to be carried forward.

Route options

An inherent part of feasibility studies is to critically examine all options and do a value engineering exercise to arrive at the most suitable solution. At the end of 1999 Arup carried out an initial pre-feasibility study as part of its East Tsim Sha Tsui station design (see pp6-8). This showed that an alignment under Canton Road, as far as West Kowloon station, was viable. However, to ensure that this was the best route, three others were critically examined for this southern section (Fig 7). Table 1 shows a simplified summary of the main objections to each. Options 2, 3 and 4 had their positive aspects, but the negative issues far outweighed any benefits.

Table 1. Route options.

Route option	Major objections
1. Canton Road	Required partial underpinning of some elevated highway structures; alignment directly beneath listed heritage buildings; some movement of sensitive buildings likely.
2. Kowloon Park Drive	Required underpinning of 16-storey YMCA building; 180m radius sub-standard curve in alignment, deemed unacceptable for railway operations; underpinning of elevated highway structures and two schools.
3. Kowloon Point	Required some reclamation of Victoria Harbour OR immersed tube for railway tunnels with enabling works for a future station if reclamation was agreed at a later date; significant underpinning of Ocean Terminal marine pier shopping complex, with severe disruption to cruise liner operations; station deemed to be remote from passenger catchment area.
4. Harbour City	Station box effectively built in the harbour; required resumption and demolition of 19-storey Star House; possible resumption or major underpinning of Omni Hong Kong Hotel; partial underpinning of Ocean Terminal; underpinning of three marine piers, two with buildings above them; re-provisioning of large seawater cooling pumphouse; station deemed to be remote from main passenger catchment area.

7. KSL route options.

Arup carried out schematic engineering solutions and team reviews, made presentations to the KCRC's senior management for all options, and wrote a confirmatory report that indicated Canton Road to be the superior solution.

Engineering solutions and physical constraints

Having agreed the preferred alignment (Fig 8), the next step reviewed potential construction options for the running tunnels and stations as well as fixing their vertical alignments, and, for the stations, the preferred locations. While the Canton Road alignment was agreed to be the most robust, it was not without its difficulties in terms of constraints and construction challenges (Table 2).

Running tunnels

There were three options for the construction method: cut-and-cover, bored, and drill-and-blast. To give the KCRC confidence that all methods were viable, two were developed:

Southern section

Option 1: Cut-and-cover beneath Salisbury Road; mostly cut-and-cover in Canton Road with small section of drill-and-blast for lower tunnel; drill-and-blast beneath former Marine Police headquarters site.

Option 2: Cut-and-cover beneath Salisbury Road (due to the shallow cover to the tunnel box and to accommodate the proposed basement car park for the Peninsular Hotel also schemed by Arup as a separate commission); bored beneath Canton Road; drill-and-blast or bored beneath former Marine police headquarters site.

Northern section

Options 1, 2: Bored from Jordan Road to Cherry Street; cut-and-cover from Cherry Street to existing Nam Cheong overrun tunnel connection.

Construction methods

Cut-and-cover: This is assumed to use either permanent diaphragm walls or in situ walls inside temporary pipe piles or sheet piles. Bottom-up sequencing is appropriate in most zones with temporary strutting of excavations.

Bored: Ground conditions are variable, ie rock, completely decomposed granite, marine deposits to fill. Mixed shield tunnel boring machines (TBMs) capable of operating in earth pressure balance, compressed air, or open mode are assumed to be appropriate. Tunnel linings are designed as precast, erected by TBM, and fully grouted behind the rings.

Drill-and-blast: This is appropriate in zones of competent rock with a horseshoe-shaped excavated cross-section and a permanent in situ concrete lining. Temporary rock bolting and shotcrete would be applied where required to ensure stability of the excavated faces prior to the permanent lining being installed.

8. Canton Road alignment.

Table 2. Major constraints to Canton Road alignment.

Constraint	Observation
New World Subway No1	Recently built pedestrian link beneath Salisbury Road crossing directly above KSL tunnels and clashing with tunnel structure.
MTR Tsuen Wan line tunnels	Existing twin-tube running tunnels beneath Nathan Road crossing directly beneath KSL tunnels with minimal clearance.
Numerous buildings flanking Salisbury Road :	Shopping mall, hotels, and hostel, all with basements, including Hong Kong s premier hotel, The Peninsula fronting Salisbury Road.
Other buildings fronting Salisbury Road:	
Hong Kong Space Museum	Event theatre sensitive to noise and vibration.
Hong Kong Cultural Centre complex	Arts, concert, and theatre venues sensitive to noise and vibration.
Peninsula Hotel car park	Proposed underground private car park under Salisbury Road to be integrated with KSL tunnels (scheme since abandoned).
Kowloon Park Drive subways	Recently extended pedestrian links crossing directly above KSL tunnels with minimal clearance.
Former Tsim Sha Tsui fire station and former Marine Police headquarters.	Listed buildings of historical importance.
Numerous buildings flanking Canton Road	Buildings of varying age: some movement-sensitive structures on shallow foundations.
Box culvert in Canton Road	Newly-constructed box culvert close to and parallel with KSL tunnels.
Kowloon Park Drive flyover	Some piers and highway ramp abutment potentially requiring underpinning for KSL tunnels.
Culverts in West Kowloon reclamation	Numerous large box culverts built across alignment, some on piles.
Yau Ma Tei interchange elevated highway structure	Some piers require underpinning for KSL tunnels.
MTR Olympic station footbridges	Some piers require underpinning for KSL tunnels.
Cherry Street highway underpass and culverts	Potential underpinning and/or re-provisioning of dual two-lane underpass and four sets of large, twin-cell, box culverts.
Olympic station property development site D	Potential underpinning of new footbridge access tower.
Prince Edward roundabout	Tunnel construction beneath part of highway interchange.

Stations

West Kowloon station

This was schemed as a rectangular box comprising two levels below ground for platform and concourse, with above-ground entrance zones, plantrooms, and ventilation structures (Fig 10). Operationally, three tracks were needed, resulting in a twin island platform layout - the outer tracks formed the main through running lines, with the centre track giving flexibility for turning back trains, stabling for an additional train at peak hours, or temporarily housing a defective train.

Two rows of twin columns flanking the escalator, stair, and lift openings gave the most economic structure. This led to reasonable spans which at later stages could be framed by any number of structural schemes as deemed appropriate - either for a full engineers' design approach or a design/build contract strategy. For the latter, Arup recommended that a reference design be carried out before inviting tenders from contractors. This would indicate a layout with structural envelopes, electrical and mechanical requirements, land take, works areas, etc.

Canton Road station

This proved a great challenge, due to its proposed location beneath one of Tsim Sha Tsui's busiest roads and flanked by a mix of building types of varying age, condition, and usage. Canton Road is relatively narrow, and so a single-level, twin-track platform was not achievable. In consequence, a stacked platform scheme was developed. Two solutions were investigated that were compatible with the two options proposed for tunnel construction.

Option 1: Cut-and-cover box

This required retaining walls under the carriageway, followed by top-down construction beneath temporary road decking (Fig 11). Whilst technically achievable, to build the box an excavation up to 28m deep would be needed. This would have meant slow, piecemeal construction with sequenced temporary traffic and pedestrian management measures, as well as very careful control of ground movements. Environmental concerns and logistical issues also had to be dealt with for the retaining structure to be built inside either a temporary pipe pile cofferdam or a permanent diaphragm wall. In planning terms, the station was a simple self-contained, column-free, rectangular box with a concourse at first basement level and two track levels stacked below this.

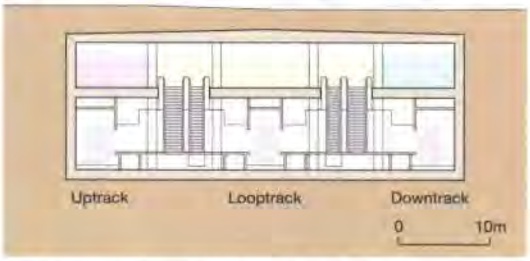
Ideas were also developed for entrances in Canton Road based on the (ideal) possibility that the road may be fully or partly pedestrianized in the future. However, public objections, including those from adjacent property owners and users, were a major concern because of the anticipated method of construction in the road's narrow width.

Option 2: Tunnelled platforms

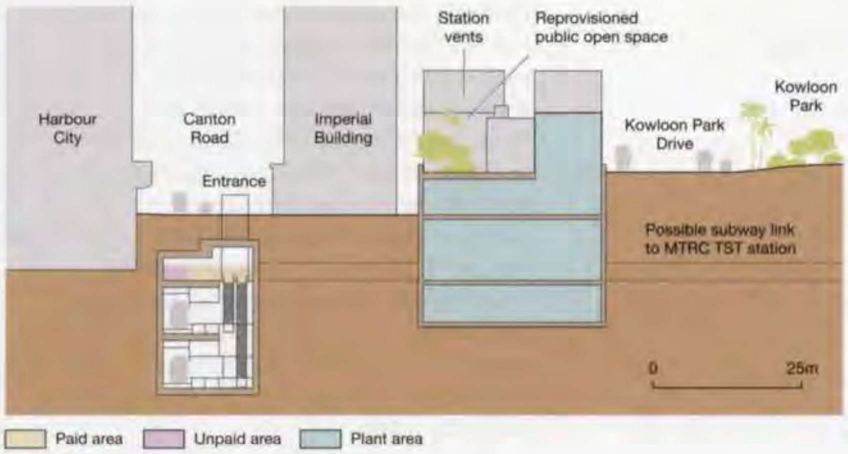
This solution provided two separated stacked platform tunnels using the concept of an "off-line" concourse box (Fig 12): a multi-level basement accommodating all station functions (concourse, plant, back-of-house, circulation, etc). The platform tunnels, each accommodating a side platform and trackway, would be much larger than the adjoining running tunnels. Intersecting passenger access adits at intervals along the platform would connect with the off-line concourse. This is similar to the arrangement of Wan Chai station on the MTR Island Line, designed by Arup in the early 1980s.

Conceptually, construction of these enlarged platform tunnels worked very well with the bored running tunnel option, as they would allow a TBM to construct the tunnels along Canton Road, laying a temporary lining in the zone of the enlarged platforms. After this, the enlargements would be

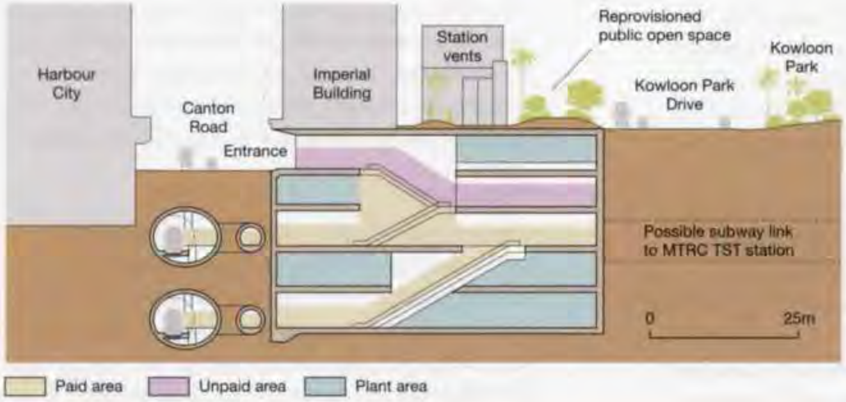
10. Cross-section of West Kowloon station.



▭ Paid area ▭ Unpaid area ▭ Plant area



11. Canton Road station: cut-and-cover box option.



12. Canton Road station: "off-line" concourse box option.

mined out from inside the temporary lining. Though this is an extremely slow process, it has distinct advantages as there is no surface disruption except for small-scale plant carrying out ground improvement for the tunnelling works. In this option, however, the amount of ground cover at tunnel crown level was only a few metres, and Arup recommended that KCRC engage a specialist tunnelling contractor to join the study should this scheme be chosen for further development.

Although the tunnelled platforms were directly under the road, construction of an off-line concourse box required land, and no vacant lots were available along Canton Road. Arup investigated schemes requiring resumption and demolition of a privately-owned, multi-storey, residential building, and some other nearby government-owned land.

Whilst technically viable and attractive in terms of minimizing surface disruption along Canton Road during construction, this solution required compulsory purchase of a private lot, which was considered undesirable. In terms of station planning, passenger movements, E/M servicing and tunnel ventilation, this option was also less favourable than a self-contained cut-and-cover box solution.

Study reporting

Arup's recommendation to the KCRC was to include both station options for Canton Road and tunnel construction methods in the final feasibility report, which also included programme comparisons and risk assessments for both options. This allowed KCRC's management board to decide which option would be formally presented to the Hong Kong government, and in due course the KCRC decided to submit both. Following this, in conjunction with the KCRC, Arup prepared a formal project proposal document that was submitted to the Hong Kong government Transport Bureau in autumn 2001, indicating the project's viability. Separate reports were also submitted to the KCRC for potential property developments at West Kowloon station and at Canton Road station for Option 2.

As a separate direct appointment, JP Morgan was responsible to the KCRC for investment and financial assessment studies, including the property development options at Canton Road and West Kowloon station.

Postscript

The KSL was accepted by government as a railway that had already been committed under the Government Railway Development Strategy 2000, and the Transport Bureau agreed to the KCRC proceeding with further design work. The KCRC took the KSL to the next stage in April 2003, when preliminary design commissions were carried out. As part of a sub-consultancy, Arup undertook the reference design of West Kowloon station, which essentially remained as the feasibility study concept, except that the third track was deleted and the station narrowed. Other consultants carried out the reference design of the railway south of West Kowloon station. Following discussions with numerous parties, the KCRC decided not to proceed with Canton Road station.

This design stage culminated in a set of reference design documents being produced to allow the KCRC to call three design/build tender packages for the entire KSL civil works in December 2004. Tenders were returned in April 2005 and to date, site work is well under way. Railway operations are planned to commence by 2009.

Conclusion

This feasibility study was a challenging undertaking, with a multi-disciplinary team identifying several alignment and station alternatives that involved review and study of railway operation and timetabling aspects for the whole of West Rail.

The study indicated that viable construction methods were available for this highly constrained alignment in a busy urban environment, and gave construction options where appropriate. While the successful design/build contractors have developed alternative construction methods for some sections of the route, it is pleasing to note that the project remains much as conceived.

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The Lok Ma Chau spur line tunnels:

design and construction

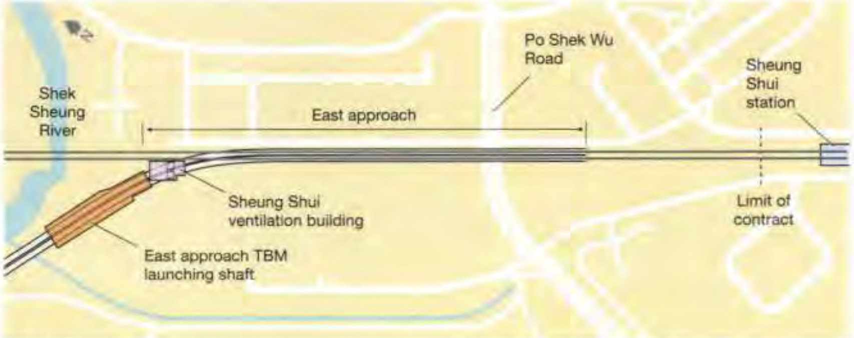
James Musgrave Glen Plumbridge

Introduction

The Lok Ma Chau spur line is a 7.4km railway from the existing Sheung Shui station on East Rail to a new Lok Ma Chau terminal. It provides a second rail connection across the border into the Shenzhen Special Economic Zone, in addition to the existing Lo Wu border crossing on East Rail. The Spur line project is significant in that, due to an interchange with the Shenzhen Metro, it brings Hong Kong and Shenzhen closer.

The project was originally conceived as a fully-elevated rail extension, and after several different alignments were examined, a route crossing the Long Valley wetland area was identified. However, this proposal was rejected due to the wetlands, as home to a number of rare bird species, being deemed environmentally sensitive. After this above-ground scheme was rejected, the KCRC appointed the highly experienced tunnelling contractor Dragages (HK) JV to develop a tunnelled alternative to pass beneath Long Valley without disturbing the sensitive habitat.

1. Project overview (EAP = emergency access point).



2. East approach layout.

Dragages had previously constructed West Rail contract DB320 (the Kwai Tsing tunnels), partly using a tunnel boring machine (TBM)[1]. From the excellent relationship built up on that project, Dragages asked Arup to join forces and develop the tunnelled scheme. The project was subsequently competitively tendered and awarded as a design/build contract to Dragages (HK) Joint Venture (DJV), comprising Bouygues Travaux Publics and Dragages (HK) Ltd. Arup acted as designer to the joint venture, providing a full multi-disciplinary design service that included architecture, structures, civil, geotechnics, tunnelling, MEP, fire, acoustics, and traffic design.

This contract (LDB201) comprised 3.2km of twin bored 8.75m overall diameter tunnels, 2km of cut-and-cover approach tunnels and ramp structures at either end, together with two ventilation buildings, noise barriers, a 55m-span footbridge north of Sheung Shui station, other ancillary works, and provision for a future station at Kwu Tung (Fig 1).

Procurement

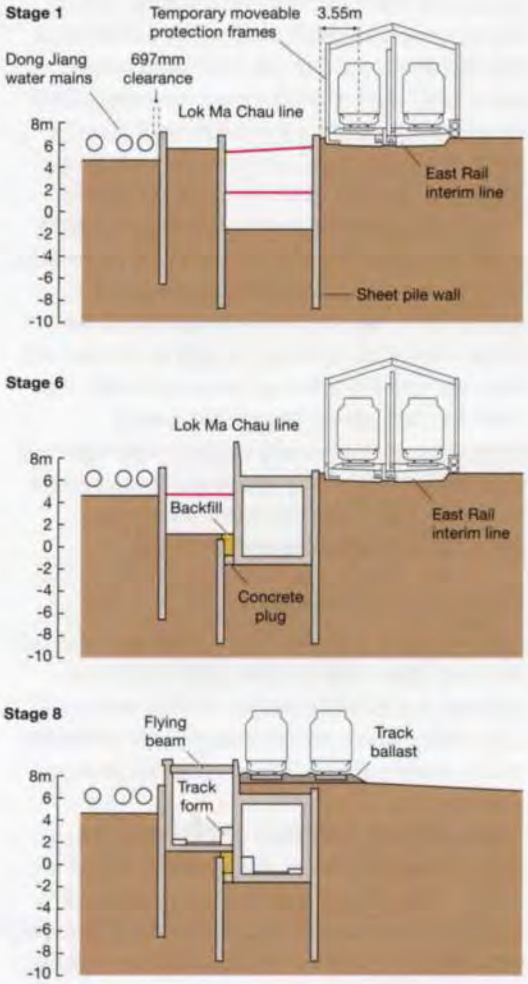
Design/build is widely recognized as being one of the most appropriate forms of contract for underground projects that are method-led. It allows the contractor to engage in the project design at an early stage, and thus ensure that it is driven by the most appropriate method of construction for the project. Design/build had been used successfully on the two then recent tunnel contracts on the KCRC West Rail project. For these, Arup had acted for Dragages and its joint venture partners as the independent checking engineer[1, 2]. Under contract LDB201, however, Dragages gave its previous designer the independent checking role, and Arup the lead design.

East approach cut-and-cover tunnels

Connecting the Lok Ma Chau spur line to East Rail required cut-and cover structures to take the tracks deep enough to commence bored tunnelling. They are some 900m long, and comprise an open ramp section as the tracks descend, and then box tunnels to connect with the bored tunnels. The approach ramps and tunnel boxes were constructed by cut-and-cover technique within temporary strutted sheet pile walls, with excavations up to 14m deep. In this area the track alignments are designed to provide a grade-separated connection between the pairs of bi-directional tracks, so that the East Rail train operations are not affected by trains joining or leaving the Lok Ma Chau tracks. Additional turnouts have also been installed to allow single-track running in an emergency should one of the tunnels be disabled or blocked for any reason (Fig 2).

To create construction space for the Lok Ma Chau permanent works, both operating East Rail lines had to be diverted away from their original location by about 10m. These diversion tracks were built adjacent to the original tracks, and then the operating railway was diverted across during non-traffic hours. This required modifications to tracks, ballast, earthworks, and structures, as well as signalling, communications, overhead line, and traction power supply. The actual modification and diversion works were carried out by KCRC using separate subcontractors, and so very close co-ordination was required between all parties to ensure that the works were carried out successfully. The modifications to the existing tracks were done during night-time possessions in non-traffic hours between 0130 and 0445, with all works carefully programmed to ensure that revenue service running could commence again at 0500 after each possession, with fallback contingency measures preprepared in the event of delays (Fig 3). In all, four changeovers were required prior to the East Rail tracks being placed on the permanent aligment.

3. East approach construction sequence.



4. East approach during construction, showing temporary protection frames.

5. East approach with noise barriers in position.

This realignment work was achieved without affecting normal train service. The geometry in this area is further complicated by the Dong Jiang water mains immediately adjacent to East Rail. These five welded steel pipes, 1.2-2.4m in diameter, provide the main water supply to Hong Kong from the East River via Shenzhen. To create sufficient headroom for the east approach tunnels, the water mains had to be diverted some 40m away from their original straight location in the area where the new line crossed under the East Rail tracks. This work was constructed under an advance works contract before the start of LDB201.

The space between the diverted water mains and the East Rail tracks was then used for the Sheung Shui ventilation building and surrounding vehicle access and parking areas.

The temporary sheet pile walls for the cut-and-cover boxes then had to be constructed in the space between the diverted East Rail tracks and the water mains, resulting in a very constricted site area, with limited access along its length (Fig 4). Installing the sheet-piles began using traditional vibratory techniques, but after several types of high-frequency hammers had been used, it was concluded that the vibration limits would not be complied with where driving was directly adjacent to the railway and the water mains. The reaction-based press-in method of installing sheet piles was therefore employed in these locations. The unique way the system holds the sheet-pile during installation was a further advantage in minimizing risk to the railway.

Careful planning of the works was needed to ensure that the programme could be met without compromising quality and safety. Real time deformation monitoring of the East Rail tracks was carried out throughout the excavation period to ensure that horizontal and vertical movement of the tracks was kept within predetermined limits.

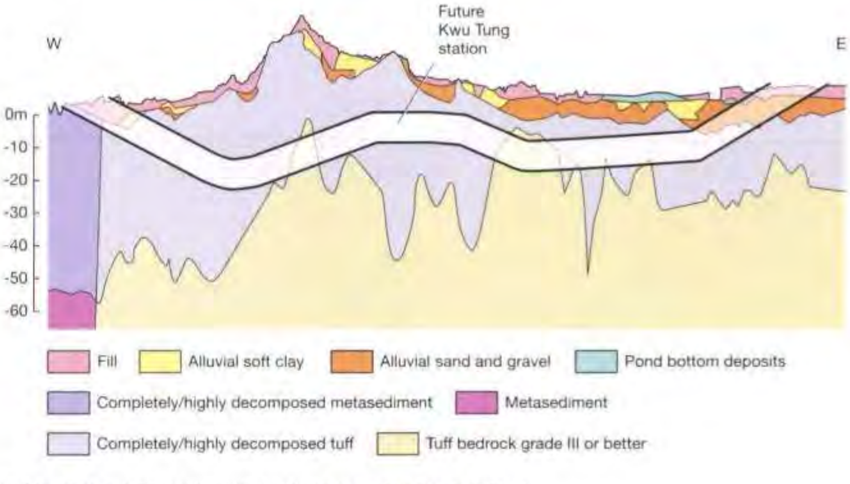
As well as monitoring the works, additional safety measures in the form of temporary moveable protection frames were used to protect the adjacent railway. These frames, spanning across the adjacent live railway, were mounted on rails so that they could be moved according to where the construction was being done.

After completion and backfilling of the cut-and-cover tunnels, the East Rail tracks were progressively rediverted to their permanent locations, with the turnouts to the Lok Ma Chau tracks installed (Fig 5). The east approach ramps were successfully completed five months ahead of programme.

TBM launch shaft

The launch shaft for the TBM drives was unusual in that the diaphragm walls required for the shaft and the pipe trough support (needed for the diversion of the water mains) immediately east of the shaft were constructed under an advance contract, prior to the LDB201 contract award. Arup designed the advance works walls directly for KCRC while Bachy Soletanche was awarded the construction contract to build these advance works.

6. The TBM *Mulan*.



7. Geological long section (vertical scale greatly exaggerated).

As the TBM spoil removal conveyer system was located within the excavated shaft, a very irregular strutting layout was required, with spans between struts of up to 12m in both plan and elevation. This, plus the proximity of the 2.4m diameter water main, necessitated significant analytical effort in designing the strutting support systems. Monitoring during excavation of the launch shaft showed strut forces to be within 90% of predicted values.

Within the 20m deep shaft, a 500mm temporary base slab for TBM launch was adopted, spanning up to 30m between the diaphragm walls. Temporary underdrainage beneath the base slab to control water pressures was required for the design.

With the launch shaft completed, a sound insulating roof was installed above it before tunnelling works began to ensure that tunnelling could continue into the night without local disturbance.

Bored tunnels

The tunnels were bored using a mixed shield TBM (named *Mulan* after the warrior heroine of Chinese folklore), able to operate in earth pressure balance (EPB), compressed air, or open mode, depending on the ground conditions. The 8.75m diameter TBM (Fig 6) is an NFM Technologies machine, built in Shanghai, and originally used on the KCRC West Rail DB320 contract for the Kwai Tsing tunnels. It has a total thrust of 6600 tonnes and nine 240kW electric motors to drive the cutter head at up to 3rpm. The cutter head was fitted with 60 discs, 450mm in diameter, and 215 soft ground tools.

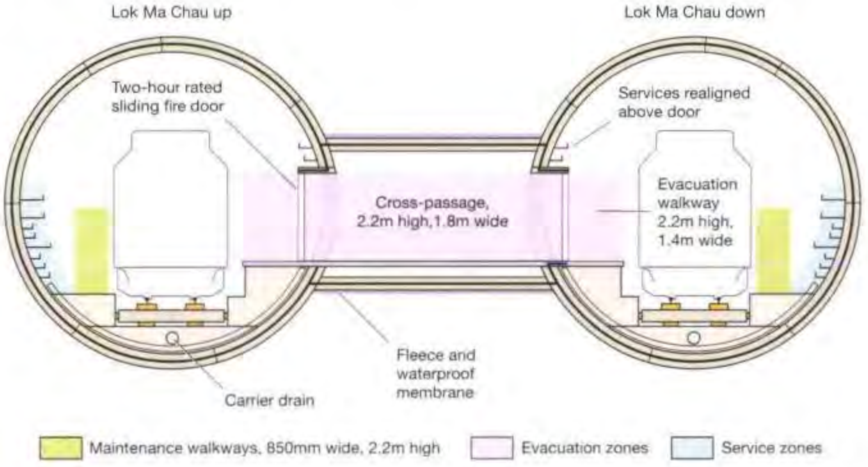
Following the TBM launch in September 2003, *Mulan* excavated the 7.2km of tunnel in 19 months, including transfer, reassembly, and relaunch in August 2004, for completion in April 2005, two months ahead of schedule. As well as transfer and relaunch from the Sheung Shui launch shaft, the TBM was also jacked through the already completed and temporarily strutted diaphragm wall excavation at Kwu Tung station on the permanent base slab, which was designed, shaped and constructed to allow this operation.

Mixed ground tunnelling

For the lengths of tunnel in soft ground and through the Long Valley wetland zone, EPB mode was adopted, but for those lengths in rock, or outside Long Valley, where the permeability was sufficiently low to prevent air loss, the compressed air mode was used.

Each tunnel ring comprises precast concrete segments erected under the protection of the tail-shield. After erection and recommencement of excavation, the annular void was uniformly backfilled with grout concurrently with the TBM progression,

8. Completed tunnel.



9. Section through typical cross-passage.

thereby minimizing settlement at ground level. Each precast ring comprises seven segments (including the key), 400mm thick, with a nominal length of 1.8m and an internal diameter of 7.625m. The segments were tapered to assist geometric control of the general alignment. The segments, which had a requirement for 0.1mm of dimensional tolerance and 1^{-12}m/s concrete permeability, were cast in mainland China and transported to Hong Kong by road.

The tunnelling process was controlled by Bouygues' in-house software *CATSBY* and *PYXIS*, which govern the machine parameters and the survey/guidance aspects respectively. The best production achieved during the project was 25 rings (45m) in one 24 hour period, with 398 rings (717m) being the best monthly progress.

Although the alignment runs through a rural area, there are many existing buildings and structures adjacent to and directly above the tunnels, ranging from residential to factory buildings in various states of repair, in use and uninhabited. Various underground utilities and above-ground power lines also cross the alignment. Arup undertook studies to determine the impact of ground movements induced by tunnelling on these structures and utilities, and to identify any prior remedial measures that might be needed. In consultation with the Government Building Authority, contingency measures were devised and agreed to deal with potential ground movement that may have caused untoward structural deformations or distress. In the event, none of these measures was required for the tunnel drives.

Ground deformation monitoring was carried out by Dragages, with their site team led by a full-time geotechnical manager, along the bored tunnel alignment. An observational approach has been found to be valuable on many tunnelling projects both in Hong Kong and around the world; in this, actual ground/structure movements are recorded as the works progress and are reviewed with respect to the initial predictions to confirm the assumptions made. This approach was adopted successfully for contract LDB201 as follows:

- comprehensive and appropriate instrumentation installed
- monitoring data processed immediately, providing direct information to the tunnelling team to optimize the tunnelling process
- appropriate alert, alarm, and action trigger levels defined
- formal notification procedures adopted to inform responsible parties within the supervising teams and the Building Authority.

Cross-passages

To comply with the fire evacuation strategy, 12 cross-passages were provided, roughly every 240m, to allow evacuation of passengers from the incident tunnel to the non-incident tunnel (Fig 9).

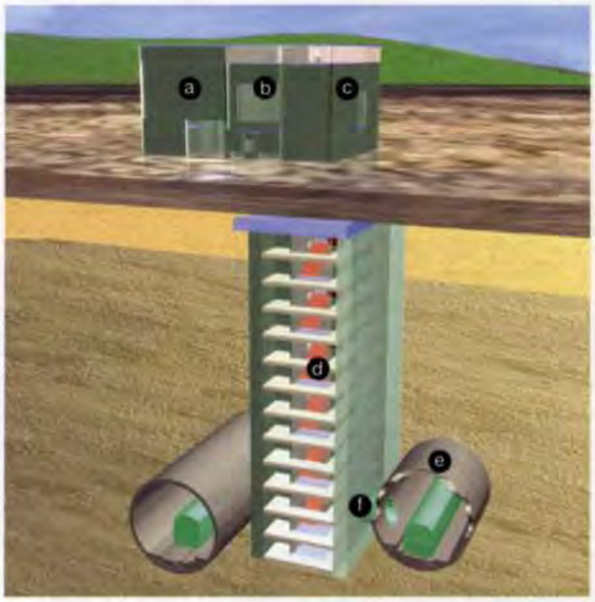
They were built mostly through completely decomposed rock, with one in highly fractured rock, and ground treatment was needed to ensure safe and stable excavation. This was generally carried out from surface when there were no access restrictions and comprised jet grouting, injection grouting, and complete substitution with lean-mix concrete. This was carried out by the Dragages specialist subcontractor, Intrafor/Bachy Soletanche JV.

The Project Environmental Permit precluded all surface works within the Long Valley wetlands area, and so the ground treatment works for three of the cross-passages had to be undertaken from within a running tunnel. In this instance, ground freezing was used to stabilize the ground. It was the first use for tunnelling works in Hong Kong of this environmentally-friendly technique which does not introduce foreign materials into the ground or require any above-ground works. The process involves pumping coolant through a series of pipes installed in the soil so as to chill it to -30°C. At this very low temperature the groundwater freezes, resulting in a significant increase in the treated soil's strength as well as becoming watertight and making the soil completely safe for tunnelling.

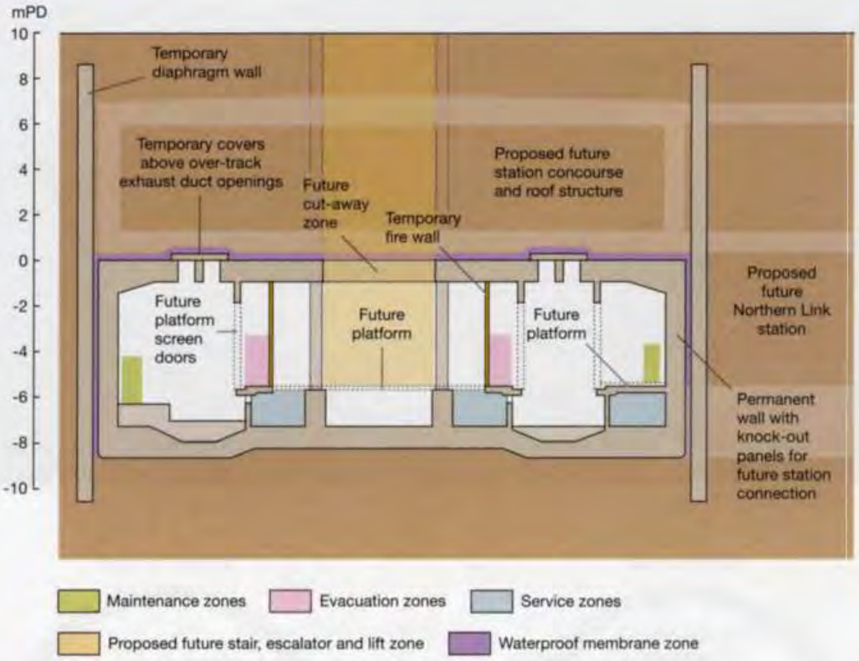
Emergency access points

There are six emergency access points (EAPs) along the length of the tunnels at up to 1km spacings, descending from ground level and connecting with tunnel walkways via protected lobbies (Fig 10). These EAPs contain a staircase and a firemen's lift, and can be used both for access to the tunnels by emergency staff and for egress from the tunnels by passengers in the event of a detrainment. The EAPs also rise above ground some one to two storeys in height, and contain plantrooms and railway-related equipment such as fire-fighting water tanks and pumps, electrical rooms, and control equipment. An emergency vehicle access road leads to a paved area for parking and turning adjacent to each EAP.

10. Emergency access point: (a) plantroom, (b) entrance, (c) firemen's lift, (d) firemen's stairs, (e) tunnel, (f) cross-passage.



11. Artist's impression of future Kwu Tung station.



12. Section through Kwu Tung station showing provisional structure.

Four are above the cut-and-cover portions of tunnel, and thus were built of in situ concrete within the open excavations. The remaining two EAPs were built within shafts formed using permanent diaphragm walls. The shafts were excavated using temporary strutting, and then constructed from the bottom up. These two structures were designed so that the lower portions of the shafts are in rock, making the connecting adits to the bored tunnel easier to construct. EAP2 at the eastern end of the bored tunnel extends some 35m below ground whilst EAP5 at the west end is roughly 39m deep.

Future Kwu Tung station

As part of the contract, KCRC required provision for a future station at Kwu Tung (Fig 11), to be built as part of the Kwu Tung New Town development identified in the Government's planning strategy for the area.

This future station was planned as a below-ground rectangular box on two levels (Fig 12). The above-ground portions will be at the east and west ends of the station, in the locations currently occupied by EAP3 and EAP4, and will house plant and ancillary facilities. Entrances will be constructed to suit the final New Town plan and road layout. The station has also been designed to serve as a possible interchange with the KCRC's future Northern Link, which is planned to provide a connection between the Lok Ma Chau spur line and West Rail at Kam Sheung Road station.

Temporary works

To minimize capital costs, only minimum provisions were constructed under contract LDB201, sufficient to allow the future construction of the station without disrupting the operating Lok Ma Chau railway. The provisions for Kwu Tung include only the lowest level of the station, which initially will house the running tunnels, and in the future will form the station platform level. This was built within temporary diaphragm walls as an in situ cut-and-cover box, and backfilled up to existing ground level (Fig 13). The excavation was designed and constructed on a very fast track programme in 11 months, so that the base slab was in place before the first TBM drive reached Kwu Tung. This required very close collaboration between the design, construction, and supervisory teams.

13. Aerial view of Kwu Tung during construction.

14. Kwu Tung under construction.

Phasing

Arup planned and sized the station, using KCRC's planning criteria and data, as an island platform configuration - well suited to the separated twin TBM tunnel bores. Two rows of in situ columns (Fig 14) support the roof slab, which in the future will become the concourse floor structure.

To minimize disruption to the operating railway, the station box has been preplanned and constructed with several permanent provisions that will allow the future station to be safely and efficiently constructed with minimum effect on the permanent structure. These include:

- overtrack exhaust duct provisions
- overtrack ventilation shaft provisions
- platform screen door top support structures
- platform structure edge strips and support walls
- end-of-platform plantrooms, ventilation opening, and louvre provision, etc.

In this initial stage, the station box operates as two distinct and separate tunnel tubes some 10m apart. To form the inner walls of these discrete tubes, fire-rated *Durasteel* panels on steel frames have been erected off the platform edge strips. By this means the future station contractor will be able to carry out and complete all platform construction including ABWF (architectural builders works and finishes) and building services inside a safe, fire-rated enclosure, prior to dismantling the *Durasteel* wall in order to install platform screen door and final platform edge works.

Since the station will not support future property development, the structure could be designed as ground bearing on the completely decomposed tuff material without need for piles. Pairs of temporary columns were also constructed to provide support to resist the considerable weight of soil on top of the roof slab.

In the future it will be necessary to re-excavate down to the roof of the running tunnels, build the concourse level and ground level structures, and then fit out the platforms at the lowest level. The temporary diaphragm walls built for the initial construction have also been designed so that they can be used to support the excavation for the future station construction. The temporary columns at platform level will be removed as concourse construction proceeds.

To avoid flotation during this future excavation work, a granular drainage layer containing a network of perforated pipes was left beneath the base slab to facilitate dewatering. This drainage system was used during the initial construction, but can also be reactivated in the future.

Provision has also been made for the future Northern Link station to be constructed alongside the Lok Ma Chau spur line station. To avoid any disruption or compromise to railway operations, a strip of future platform slab was built on the north side of the station box, serving initially as a maintenance walkway. Knock-out panels have also been allowed for through the perimeter wall for future cross-platform interchange.

West approach cut-and-cover tunnels

At the west end of the contract, the tracks ascend to grade and then onto adjoining viaducts constructed by others under a separate "engineer's design" contract. The bored tunnels were driven to a point where the soil just prevents flotation (approximately one tunnel diameter), and then the structure changes to cut-and-cover box tunnel. A temporary retrieval shaft was built at the end of the bored tunnels to extract the TBM. This comprises in situ diaphragm walls, with "soft eyes" formed using glass fibre reinforced plastic (GFRP) reinforcement to allow the TBM to bore through the end wall into the shaft (Fig 15).

The cut-and-cover tunnels are approximately 450m long, plus a 100m long open ramp section within which the tracks descend from ground level into the twin cell running tunnel box that passes under the Chau Tau ventilation building and connects with the bored tunnels (Fig 16). A crossover approximately 100m long is provided underneath the vent building to allow single track running in degraded operations (Fig 17).

15. West approach layout.

Sheung Shui and Chau Tau ventilation buildings

These are at the east and west portals respectively of the tunnels, and provide airflow in both normal and emergency modes to the tunnels. The two-storey in situ reinforced concrete buildings are partly above and partly below ground, and supported both on the ground-bearing cut-and-cover box tunnels and on friction piles in the ground to one side. Using these different support conditions required detailed analysis of potential differential settlement effects, and the construction sequence had to be carefully controlled. The buildings accommodate electrical, transformer, and air compressor rooms in addition to the main ventilation plant connecting to the cut-and cover tunnels.

Conclusion

From the initial concept of a wholly elevated railway through an environmentally sensitive wetland, the KCRC successfully managed the re-engineering and construction of a superior underground solution for this section of the Lok Ma Chau spur line. This was achieved using a design/build procurement contract completed within budget and programme.

Close collaboration between the contractor's design management staff, construction managers, geotechnical manager, and the multidisciplinary design team resulted in common goals being achieved with minimal abortive work or loss of time during the contract's initial design stages. Similar close collaboration between the KCRC's site-based engineers representative and construction management team and the contractors team at all levels resulted in good communication lines, common aims for quality, safety, programme, cost-effectiveness, and successful interfacing with the Corporation's appointed system-wide contractors.

Following completion of the contract in October 2006, preoperational trials were carried out in 2007 before the service opened to the public on 15 August 2007.

16. Aerial photograph of west approach under construction.

Glen Plumbridge is a Director of Arup in Hong Kong, and was project manager for the Lok Ma Chau spur line project.

James Musgrave is an Associate Director of Arup in Hong Kong, and was the civil and structural design team leader for the Lok Ma Chau spur line project.

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17. Crossover at west approach.

Tai Wai maintenance centre:

planning, design, and construction

Kennedy Cheung Charles Chor David Pegg

Background

In the continued expansion of Hong Kong's urban railway network since the early 1970s, it was soon recognized that to use land exclusively for mass transit facilities, like railway maintenance centres ("depots"), would effectively sterilize large areas. Integrating these depots with podium structures to support future air rights development above has proven a successful model for the financial viability and investment potential of new rail schemes, and there are now many examples across Hong Kong.

The KCRC's Tai Wai maintenance centre and associated overrun tracks cover around 14ha; above Tai Wai maintenance centre itself, a $65\ 000m^2$ podium structure has been built to support future air rights development. The 2km overrun tracks nearby were constructed close to the existing East Rail line, requiring stringent planning, operator co-ordination, and safety management to ensure that service on the line was uninterrupted.

As part of the KCRC East Rail extensions project, MOS Rail runs for some 11.4km from Wu Kai Sha in the north-eastern New Territories southwards to Tai Wai, where it interchanges with the existing KCRC East Rail. Tai Wai maintenance centre is a key facility in MOS Rail's operation, and in addition to maintenance and stabling facilities for the entire fleet of trains, it also houses offices and training facilities for KCRC operations staff.

Implementation of the project began in July 1999 with the award of the detailed design to Arup in Hong Kong. Gammon Construction Ltd was appointed main civil works contractor for a contract sum of HK$1331.7M. Work started on site in February 2001 and successful delivery of the project on programme enabled revenue services to begin in December 2004.

Arup scope of services

This comprised the depot layout and alignment design; architectural planning and detailed architectural design; operability review of the depot layout; workshop sizing and specification of specialist depot equipment; civil, structural and building services engineering for all railway-related facilities and buildings, civil and structural engineering design of the foundations and podium structure supporting future topside development; fire engineering; systems assurance; construction planning; preparation of tender documentation; and construction supervision.

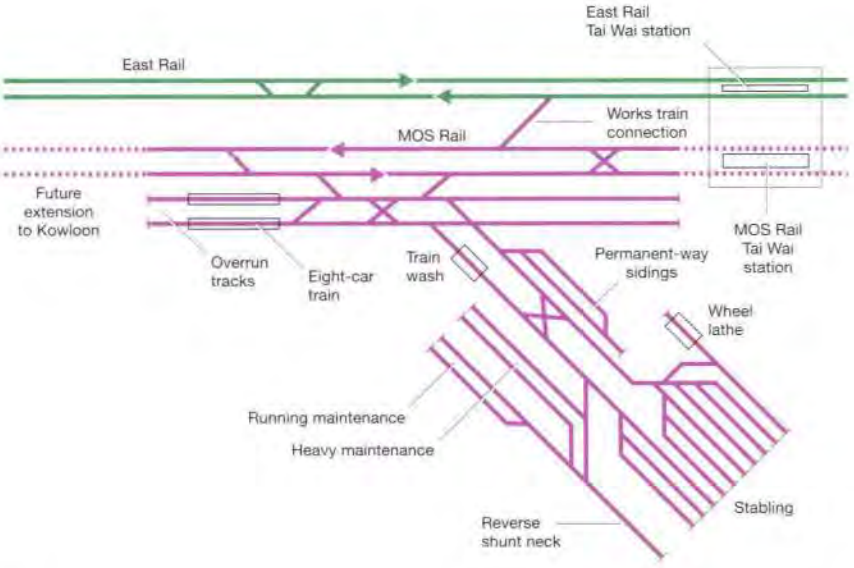
The Arup team comprised 50 design staff at the peak for detail design production and 90 site supervision staff to oversee construction in accordance with the requirements of the Hong Kong Buildings Ordinance.

Planning

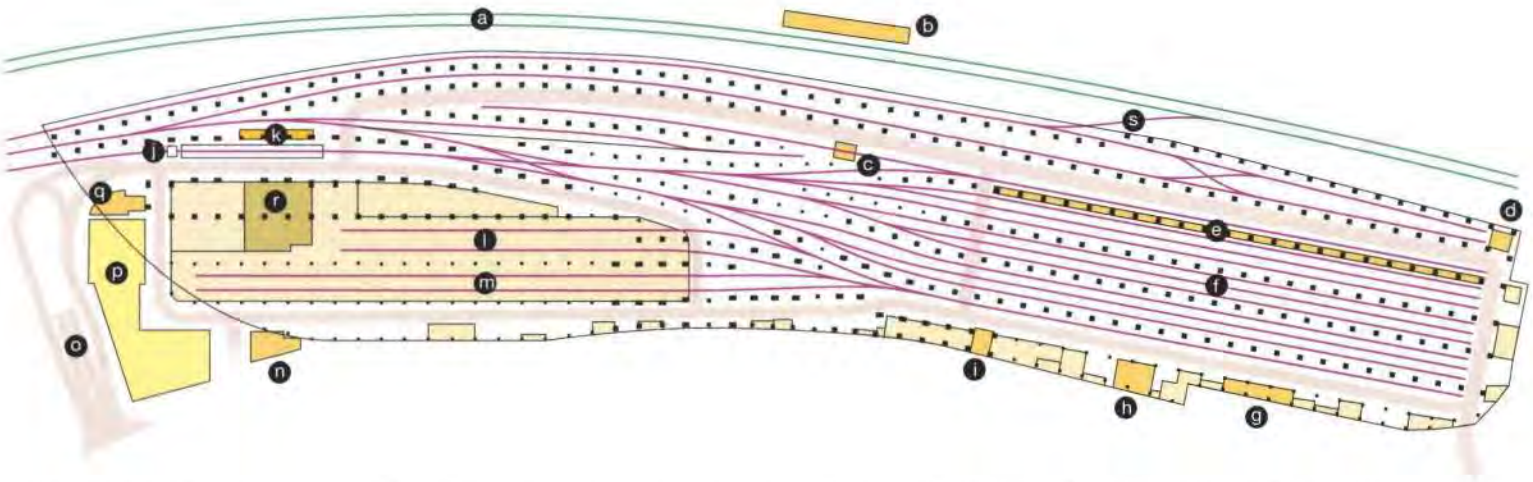
Track and functional layout

The site is close to Tai Wai station, MOS Rail's terminal and interchange with East Rail, and lies parallel to the existing East Rail line. The site is typically at +8.5mPD elevation (8.5m above Public Datum), significantly lower than the main line track level of +21mPD at Tai Wai station.

The relationship of the maintenance centre to the main line was studied extensively to determine an arrangement that would satisfy operational security, geometrical constraints, and effective use of the site area. The significant difference in level precluded a doubled-ended configuration, so the recommended solution was to extend the MOS main line parallel with East Rail south of Tai Wai to form tail tracks at the same level as the site, enabling a reverse shunt into a single-ended maintenance centre configuration (Fig 1). The layout was designed from the outset to enable future southwards extension of the main line to Kowloon for the potential Shatin to Central Link.



1. Single-line track layout showing the configuration of switches and crossing adopted at TWMC.



(a) East Rail, (b) Switchgear compound, (c) Underfloor wheel lathe, (d) EMU cleaning store, (e) Heavy cleaning platforms, (f) Stabling area, (g) Dangerous goods store, (h) Substation "C", (i) Plumbing and fire service, (j) Vehicle monitoring equipment, (k) Train wash, (l) Heavy maintenance track, (m) Running maintenance track, (n) Substation"B", (o) Access ramp for future podium development, (p) Administration building and training centre, (q) Guard house / fire control centre, (r) Main depot building (s) Works train connection.

2. Tai Wai maintenance centre layout.

The operations and maintenance plan required Tai Wai maintenance centre to be the:

- stabling centre for the entire MOS Rail fleet, totalling 80 trains, initially as four-car sets and ultimately as eight-car sets
- heavy and running maintenance centre for fleet
- washing centre for all train sets on entry to the maintenance centre
- maintenance centre for MOS Rail trackside and station equipment
- heavy cleaning centre for the fleet
- underfloor wheel lathe facility for the fleet
- stabling centre for MOS Rail permanent way and track maintenance vehicles.

A key factor was making effective use of the site, as it was only wide enough for 11 tracks. This was barely sufficient for stabling and required innovative planning for all the requirements to be accommodated. The Electric Multiple Unit (EMU)-related functions dominated configuration of the track layout, and the priorities in developing the layout were generally set as follows:

- delivery of trains into service at a maximum frequency of 15/hour
- retrieval of trains from service at a maximum frequency of 15/hour
- scheduled and unscheduled running maintenance and internal cleaning
- external washing
- recovery of immobilized trains from the main line
- emergency lifting for replacement of bogies
- wheel turning
- scheduled maintenance and heavy overhaul
- permanent way support.

A works train connection between MOS Rail and East Rail was a high priority, so that maintenance facilities could be shared between Tai Wai maintenance centre and the East Rail maintenance centre at Ho Tung Lau.

Introducing a shunt neck track by the stabling tracks enabled Tai Wai maintenance centre's facilities to be placed alongside the stabling track entry fan, and shared use of a stabling track with the heavy cleaning berth and access track to the underfloor wheel lathe enabled all the required facilities to be located at the site (Fig 2). Due to the frequency of usage between the stabling and maintenance tracks, this arrangement was favoured as it would minimize shunting movements in Tai Wai maintenance centre.

In normal operation the extension of the MOS Rail main line forms an overrun beyond Tai Wai station to facilitate easy turn back of services. Launching and retrieval of trains requires the EMUs to be held at the end of the tail tracks, enabling transfer of drivers from one end of the train to the other as they reverse between the maintenance centre and main line.

This "step back" arrangement necessitated two berths at the end of the tail tracks to maintain the line's operational headway.

Accommodation planning

The layout of Tai Wai maintenance centre was planned with the operational and non-operational areas clearly separated so that staff movement routes are segregated from train movements. Planning was developed on workflow principles so that running and heavy maintenance tracks, workshops and stores were logically positioned, enabling components and equipment undergoing first or second line maintenance to be easily mounted and removed from the EMUs.

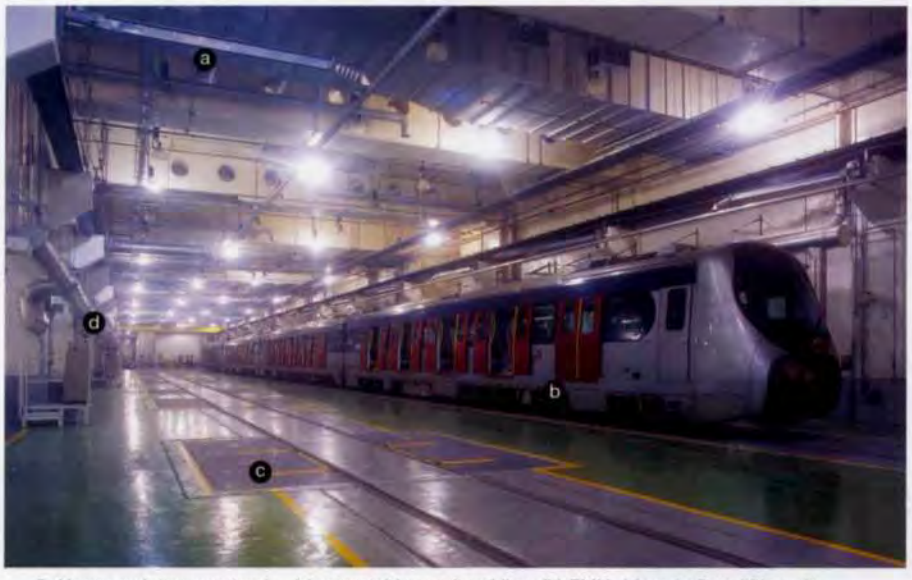
Tai Wai maintenance centre was conceived as a series of buildings of various sizes, most of them beneath the development podium. The buildings are generally single-storey but some mezzanine levels were introduced where appropriate to efficiently use the available space.

The maintenance workshops, offices, locker rooms, plantrooms and storage facilities are located within a main depot building (MDB), with ancillary buildings for plantrooms and dangerous goods stores located around the site to suit functional requirements.

Next to the MDB is a separate three-storey administration building with classrooms, workshops, a cab simulator, training facilities, chiller plant, substation, and staff canteen.

3. Running maintenance track - (a) high level access, (b) spot cooling ducts, (c) maintenance pit.

4. Spot cooling ducts at low level.



5. Heavy maintenance track - (a) retractable overhead line, (b) EMU, (c) underfloor lifting pit, (d) Spot cooling ducts.

Maintenance facilities

Tai Wai maintenance centre undertakes all heavy and routine maintenance for the MOS Rail fleet except major overhauls and bogie repair, which are shared with Ho Tung Lau where spare capacity and space exists.

The running maintenance tracks comprise two depressed floor tracks of eight-car length (Fig 3). These are used for routine scheduled and unscheduled maintenance, the depressed floor enabling easy access to the full length of the train's sub-frame. Above, a continuous steel platform gives access to roof-mounted equipment such as the pantograph and air-conditioning units. Worker access to this high level platform, and control of the 2 tonne overhead crane serving the tracks, is interlocked with the overhead line and only possible when the overhead line is not live.

Spot cooling is an innovative way to provide ventilation to workers efficiently without air-conditioning the entire maintenance shed. It is integrated with the track support at low level (Fig 4), whilst at high level, workers can direct cool air to their workplace from directional ducts.

The heavy maintenance tracks comprise two lifting tracks of four-car train length (Fig 5). One track is fitted with an underfloor lifting system for either individual cars or a complete coupled four-car train. The other track has a strengthened floor to enable lifting by mobile jacks. Turntables at the ends of the lifting tracks enable bogies to be removed and taken by road to Ho Tung Lau for maintenance.

The tracks are also served by a 10 tonne overhead crane, which enables transport of all components removed from the EMU to workshops at the end and to the sides of the heavy maintenance tracks. The heavy lifting tracks are fitted with a retractable overhead line so that EMUs can access the heavy maintenance area without the need for shunting assistance.

Train washing facilities

All trains can be washed from a detergent wash along the entry track before entering the stabling tracks, which eliminates unnecessary shunting within the maintenance centre. The train wash plant is fitted with brushes for cab ends, sides, eaves, and skirt. To maximixe water recycling for future washing, a recirculation pit to remove sediment and neutralize effluent is alongside the train wash plant.

Permanent way facilities

The space alongside the track fan area is available for storing track maintenance vehicles, and electric shunting locomotives are provided within the maintenance centre.

Underfloor wheel lathe

A single-headed underfloor wheel lathe adjacent to the heavy cleaning track is used for turning and grinding EMU wheelsets (Fig 6). EMUs are all operated using a dedicated electric shunter through the lathe and the wheel sets trimmed without detaching the wheel set from the bogie assembly. The wheel lathe is fitted with an automatic system to remove swarf (metal chippings and shavings).

Provision for air-rights property development

The goal was complete segregation between the railway and property zones, so that future development above the maintenance centre would neither have significant constraints on its flexibility nor disrupt railway services. The team developed concepts to segregate the two areas so that access, fire separation, and utility servicing to the topside development are all isolated from the railway operations below (Fig 7).

Integrating property development with the maintenance centre required enabling works for the former to be committed as an initial capital cost of the latter. In the long term, however, this provides a ready foundation for a rapid start to the residential properties once the topside air rights development programme has been confirmed.

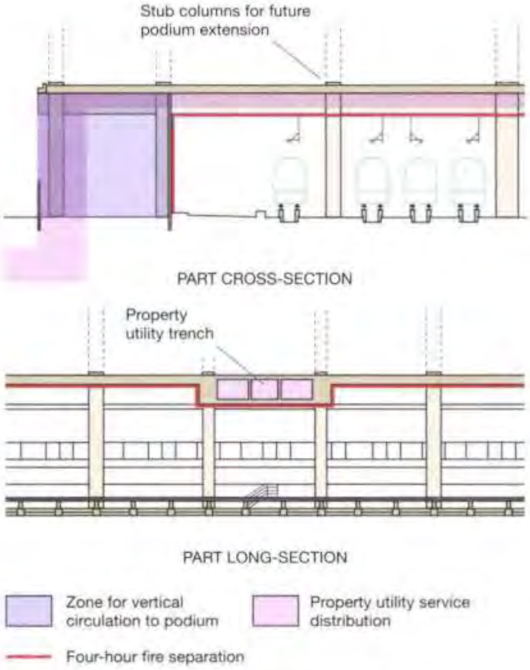
Design

Podium

The 65 000m^2 maintenance centre podium was designed to support a future topside development comprising:

- residential towers
- schools and other government and institutional facilities
- podium level car parking
- podium level landscaping areas
- two-storey clubhouse for the future topside development
- vehicle access by a dedicated ramp at the south of the site.

6. Underfloor wheel lathe.



7. Property development provisions.

Foundation system

The contractor's foundation design used fewer, but larger diameter, bored piles than originally planned. Under the proposed tower blocks there are 422 bored piles 1.5m to 2.9m in diameter, with bell-outs up to 4.35m, founded on rock with a permissible bearing capacity of 5mPa. There are also 1109 socketted pre-bored H-piles under the retail, clubhouse and landscape areas.

The foundation level structure transfers vertical loads from the columns to the piles, and resists lateral loads in frame action. Where a column is supported off a group of piles, a pilecap large and deep enough to transfer the loads has been provided with significant rotational stiffness at the base of the column to restrain it against bending from lateral loads. This enables tie beams to be deleted between pilecaps, thus simplifying construction and easing the co-ordination of underground services.

Podium structure

The podium structure is designed to:

- carry vertical loads from the slabs to the columns
- resist lateral loading from the development above in frame action
- carry 15kPa construction loads from above in the future
- provide a four-hour fire separation between the railway operational area below and the development area above
- give environmental protection to the railway operational area.

The maintenance centre trackwork and the proposed topside development required co-ordination to ensure sufficient vertical support beneath the tower locations, and columns were positioned beyond the structure gauge of the railway. Where the tracks are parallel this co-ordination was relatively simple, but in areas where they diverged, such as the "fans" leading to the stabling sidings, the geometry was complex and resulted in irregular spacings for column support beneath the proposed footprints of the topside developments. A structural solution comprising downstand beams transversely and a one-way spanning flat slab longitudinally permitted flexibility in locating columns between the irregular track spacings while retaining a symmetrical structure for construction and analysis.

The structure behaves quite differently under lateral load in the transverse and longitudinal directions. Transversely the spans are generally longer, typically 15m-22m, comprising beams 1.5m wide and 2.25m deep with columns oriented on their weak axis. As a result the beams have to carry a large proportion of the horizontal load in frame action. Longitudinally, the spans are comparatively short, typically 8m-10m, and comprise 425mm flat slabs but with the columns oriented on their strong axis. This means that most of the horizontal load is transferred directly into the columns in cantilever action and beams are not required. The one-way spanning slab in the longitudinal direction is therefore achievable.

The flat slab solution offered several advantages, which included:

- increased space between the transverse beams for services
- a smooth soffit, which assists in smoke and air movement
- simplified design, as the columns are irregular longitudinally over much of the centre
- simplified construction, as less shuttering and secondary beams are required.

The podium structure was analyzed using conventional linear elastic methods. A series of 2-D plane frames both transversely and longitudinally were analyzed for ultimate limit state and serviceability limit load combinations.

Fire engineering

The large operational spaces offered many opportunities for fire engineering, and significant savings were achieved by adopting fire-engineered designs in lieu of prescriptive installations. For example, sprinklers and drenchers were eliminated throughout the stabling and track fan areas.

The basic fire strategy examined the functional requirements and fire risk within each area.

8. Stabling tracks.

Where occupancy is low, or where EMUs pass through usually without stopping, the team demonstrated that smoke control measures maintaining a smoke clear height of 3m would enable operational staff to escape to a point of safety if a fire occurred.

The podium structure with its transverse beams and flat slab was ideally suited to splitting the stabling and track fans areas into smoke compartments, where the smoke generated in a fire could be safely contained and extracted at high level.

Maintenance centre equipment

Maintenance of EMUs commences at entry, where automated vehicle monitoring equipment detects unusual wear and tear of the pantograph, wheel, and brake pad, enabling fault data to be automatically transmitted to the control centre.

This enables the maintenance centre controller to direct EMUs to running maintenance tracks for fault diagnosis, and thus improve maintenance efficiency and fleet reliability.

Three state-of-the-art laser imaging monitors, unique to Hong Kong, are installed on the entry tracks to the depot (Fig 9). These are:

- a pantograph wear monitoring system to measure the profile of the carbon strips on the pantograph; this minimizes the need for train top inspections, and enables more frequent checking and earlier detection of defects

9. Vehicle monitoring systems:

(a) brake pad wear

(b) pantograph wear

(c) wheel profile wear.

- a wheel profile monitoring system to measure the diameter, wheelset back gauge, and flange thickness and height for every vehicle returning to the depot; this detects unusual wear and tear, so that wheel sets can be maintained to ensure safe operations and low wheel noise
- a brake pad wear monitoring system to measure brake pad thickness of every wheel returning to the depot.

Adopting these systems enables more frequent monitoring of the key rolling stock components that affect fleet performance and reliability.

Construction

Foundations and superstructure

The contractor's intended construction sequence was to start piling in the south of the site and move northward zone by zone. Then the substructure and superstructures would follow progressively from south to north. Three tower cranes were planned to be used, two of them travelling along the edge of the site and the other static. The property development slab over the maintenance centre was to be constructed using two sets of travelling falsework, each working across a zone before being dismantled and re-erected in the next zone.

The rockhead in parts of the site was deeper and more steeply sloping than anticipated, particularly in the south, so an intense programme of predrilling mapped out the rockhead in advance of piling, with more than 40 predrill rigs mobilized at the peak of investigation. This revealed several areas across the site where rockhead was considerably deeper than expected, requiring deeper piles; in addition, neighbouring pile bases needed to be lowered to comply with load-shedding requirements.

To maintain pile production, the initial construction sequence had to be revised. A total of 33 cranes, 16 reverse circulation drills, five casing rotators, seven bell-out bits, and 11 H-pile rigs were on site simultaneously at one stage (Figs 10, 11). In total, 14 300m of bored pile was installed, compared to an anticipated 11 700m, the deepest bored pile being 76m compared to an envisaged maximum of 48m. The total length and maximum depths of pre-bored H-piles were approximately the same as anticipated.

The fragmented pattern of piling completion had a knock-on effect on podium slab construction. Travelling falsework for relatively small, separated areas was no longer viable, so a more traditional, static system was used. This allowed the planning flexibility needed, but also required the use of over 1700 tonnes of scaffolding. The number of tower cranes was increased to seven, all static, distributed evenly along the centre of the site.

Work close to East Rail

A total length of around 1700m of retaining wall up to 10m high was included in the original contract provisions for the overrun tracks, and a further 300m of enabling works for the future Shatin-Central Link was instructed during the contract.

These retaining walls had to be built within the existing KCRC East Rail embankment and very close to the East Rail running lines. In addition, many groups of bored piles and pre-bored H-piles to support the podium had to be built within the toe of the embankment.

The safe and uninterrupted operation of East Rail was of paramount importance during construction. Among the precautions were a trackside hoarding along the full length of the site to prevent unauthorized access; three full-time KCRC-qualified look-out men with a clear view of the site and tracks; and three emergency telephones linked directly to the senior train controller. During piling close to the railway, 5m high moveable catch fences were provided at each pile position to protect the trains from dust, mud, or impact.

10. Piling plant at peak production.

11. (a) Podium slab (b) podium columns, (c) East Rail protection.

12. Temporary excavation support adjacent to East Rail - (a) East Rail, (b) retaining walls under construction.

13. (a) East Rail lines, (b) podium access ramp, (c) administration building and training centre, (d) podium with completed maintenance centre below, (e) Tai Wai station.

For safety, the East Rail tracks, overhead line masts, platform equipment modules, and other trackside structures were closely monitored for movement. In particular, track settlement, twist, and cant were to be reported every 2m, and overhead line masts checked for tilt and settlement.

To achieve this accurately and safely, an automatic deformation monitoring system (ADMS) was installed using seven automated theodolites sending readings by cable back to a computer centre on site. Over 1000 reflective prisms were installed along the track and on trackside structures.

The theodolites made two traverses per day and the survey data received from the ADMS was analyzed at the site computer centre. Reports were produced twice a day; one in the afternoon and one at 0400 hours. The afternoon report was reviewed in daily meetings to check for adverse trends developing, and following the 0400 hours report, a line survey message was faxed by the contractor to KCRC's East Rail control centre before 0430 daily. This was studied by the KCRC team each morning to confirm that it was safe to despatch the first train of the day at 0500. The ADMS operated continually from July 2001 to July 2003.

The temporary works for the retaining walls comprised two rows of strutted sheet piles in the embankment (Fig 12), installed using silent hydraulic piling machines to reduce vibration of the track or embankment. Ground anchors were also tried instead of struts, but were not widely used due to settlement of the track during installation. Where hard ground capable of resisting the silent machine was found below the embankment, the area was first stitch drilled. In one area of high very hard ground, about 60m long, it was necessary to install a pipe-pile wall instead of sheet piling.

A strict permit to operate/permit to move procedure was enforced for all heavy plant such as cranes or piling equipment operating within 30m of the track. A fail-safe principle was adopted when positioning heavy plant so that, even if a jib collapsed or plant overturned, there would be no encroachment beyond the site hoarding. Audible alarms were also fitted to cranes to alert operators and supervisors that a jib was nearing a critical direction.

These safety measures ensured that construction of all works within the railway protection zone occurred without major incident and enabled KCRC train controllers to quickly implement temporary local speed restrictions if movements exceeded alarm limits until such time that the main line tracks could be relevelled and tamped during night possessions.

Conclusion

The Tai Wai maintenance centre project involved the design and construction of a single facility to serve two fundamentally different objectives: firstly, provision of a world-class facility for stabling and maintaining the MOS Rail fleet that gives the residents of the north-eastern New Territories reliable rail services; and secondly to provide a platform above the maintenance centre from which to build further residential development to stimulate patronage growth and generate further revenue for the KCRC.

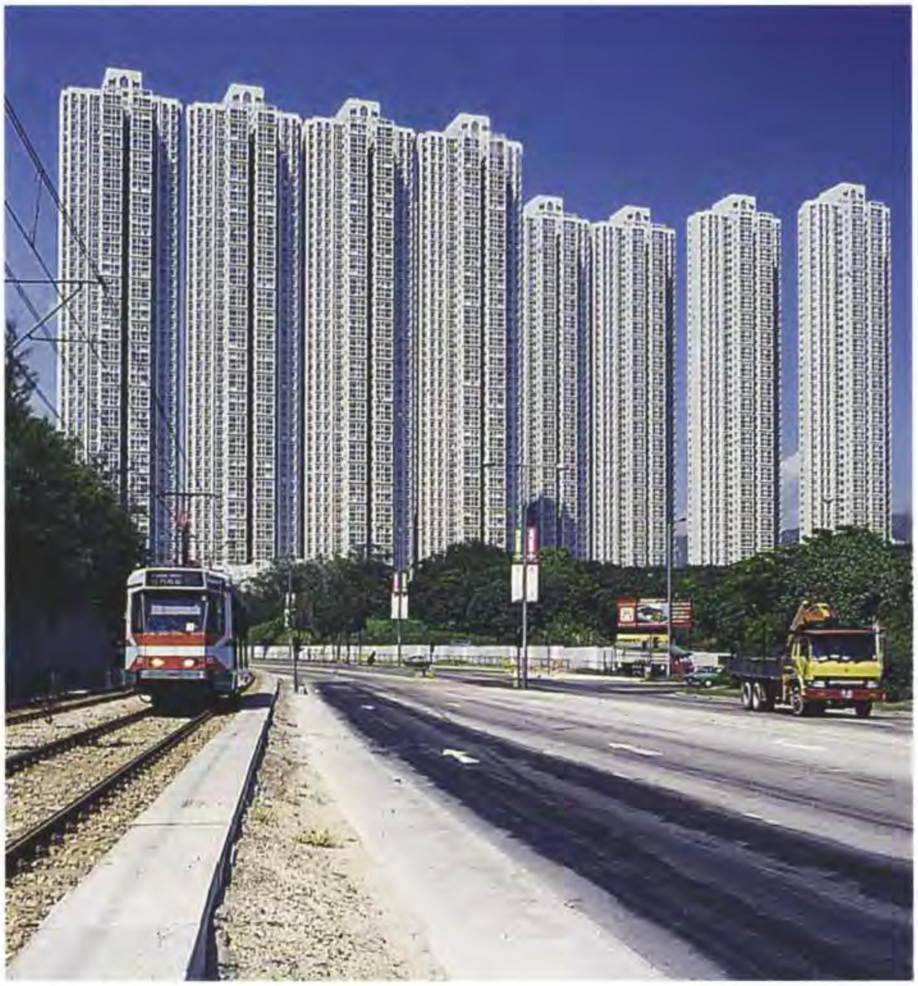
Tai Wai maintenance centre has successfully combined these objectives to create a world-class facility that is efficient, utilizes state-of-the-art systems for railway maintenance, and ultimately will be absorbed and integrated into the urban landscape with minimal noise and visual impact.

David Pegg is an Associate Director of Arup's Hong Kong Group D. He acted as deputy project manager for Tai Wai maintenance centre throughout design and construction.

Charles Chor acted as the KCRC's project engineer for Tai Wai maintenance centre through the detailed design and construction period.

Kennedy Cheung acted as project manager for Gammon Construction Ltd throughout the Tai Wai maintenance centre construction contract.

This is an edited version of a paper submitted in response to the Hong Kong Institution of Engineering call for papers on civil engineering infrastructure projects.



1. The Sun Tuen Mun Centre development.

Railway-related property development

Berny Ng

Introduction

Before 1980, the Kowloon-Canton Railway was simply a transportation system to link the the New Territories' rural districts and towns with Kowloon, and the major means of transporting goods from mainland China to Hong Kong. However, very limited land availability and extremely high land values on both Hong Kong Island and the Kowloon Peninsula led to rapid population expansion in the New Territories, and during the early 1980s the KCRC undertook large-scale upgrading works, including redevelopment of Ho Tung Lau maintenance centre at Fo Tan, near Shatin in the New Territories.

Following the MTRC's success with railway-related developments, the KCRC embarked on its first large-scale residential development (Jubilee Garden), completed in the mid-1980s above a podium over the stabling tracks at Ho Tung Lau. The success of this enabled the KCRC to plan and build further developments, mainly above depot or freightyard areas, during the rest of the 1980s and 1990s.

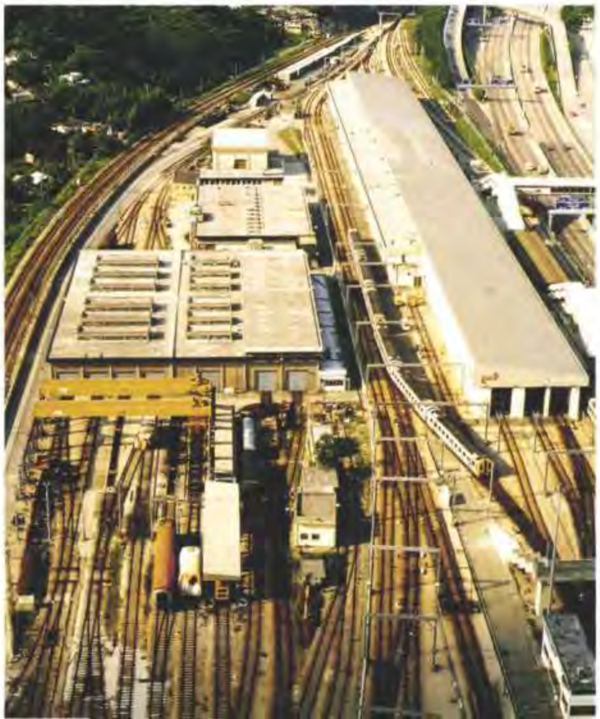
1986-2002

In 1986, a joint venture of Sun Hung Kai Properties and the KCRC appointed Arup as structural consultant for the Sun Tuen Mun Centre development, a mix of commercial, residential, and car parking to be built over the stabling tracks at the Tuen Mun light rail maintenance centre in the North West New Territories. Arup had already been appointed by the turnkey contractor for the full engineering design of the new LRT system including the reinforced concrete podium above the stabling area, schemed and designed to cater for the future development.

Ten 44-storey residential towers were built above three levels of commercial and car parking spaces on top of the podium deck (Fig 1). The 114m high towers, of shear wall construction, are supported on a 3.4m deep grillage of transfer beams at podium level carried by large columns placed between the stabling tracks. These columns, the largest of which are 3.3m x 1.2m, are carried on hand-dug caissons up to 2.8m diameter with belled-out bases up to 5.6m diameter.

In 1990, the same joint venture appointed Arup as civil/structural/geotechnical engineer for the Royal Ascot residential development above the new 9ha integrated Ho Tung Lau maintenance centre. As lead consultant, Arup had already led a team from feasibility through to commissioning this state-of-the-art maintenance and repair centre. To allow the existing facility (Fig 2) to operate continuously and virtually unhindered, the maintenance centre (Fig 3) was built in three phases between 1989 and 1995, during which construction of the residential blocks also began in June 1991 (Fig 4).

2. Ho Tung Lau maintenance centre before redevelopment.



3. Ho Tung Lau maintenance centre.

4. Development under construction above Ho Tung Lau maintenance centre.

5. Royal Ascot development at Ho Tung Lau complete.

The Royal Ascot development has over 2400 medium-range apartments in 10 tower blocks from 33-40 storeys, whilst the three-level podium structure provides over 1900 car parking spaces as well as shopping and extensive sport and leisure facilities for the residents. The first phase (four towers) was completed in November 1993, and were fully occupied by April 1997. Residents enjoy spectacular views overlooking the nearby Shatin Racecourse from this, the district's outstanding residential development (Fig 5).

The success of the Royal Ascot scheme led the KCRC to commission a full potential property development study when it undertook expansion of its existing East Rail system and the new Ma On Shan line in the late 1990s.

Between 1998 and 2000 Arup was appointed as the term civil/structural/geotechnical engineering consultant to provide technical support for a lead architect looking at potential property development above and near all existing and future railway stations and depots, including:

- Ho Tung Lau maintenance centre site A: residential development study
- Millennia Tower study at Hung Hom station north fan area
- new KCRC headquarters building study at East Tsim Sha Tsui station
- Tai Wai maintenance centre topside residential development study
- Tai Wai station topside residential development study
- Che Kung Temple station topside residential development study
- Wu Kai Sha station topside residential development study
- potential mixed commercial and residential development complex at Fo Tan dairy farm Site, Fo Tan station and freightyard ste.

Arup's in-depth studies for foundation options along and near existing railway tracks and other railway infrastructure took into account railway operations, impact to railway equipment, constructability of different foundation types, impact to public safety, and construction programme.

For superstructure works, the structural system above existing live tracks and railway equipment was integrated to ensure no compromise to the KCRC's operational requirements during the construction period. This required careful consideration of constructability issues in terms of safety, time, and cost.

In 1997 the KCRC with Cheung Kong Holdings appointed Arup as structural/geotechnical/façade/traffic engineering consultant for a 5ha development on a newly-completed podium above the KCRC's freightyard adjoining Hung Hom station, to contain a mix of commercial and residential blocks. Since named the Metropolis, this development comprises a 15-storey office block, two 17-storey serviced apartment towers with 1324 flats, and the Harbour Plaza Metropolis Hotel with 690 guestrooms and suites. All four tower blocks sit above a three-level shopping mall built on the podium deck over the freightyard. The Metropolis was completed in 2002 (Fig 6).

Following rebuilding of Ho Tung Lau maintenance centre, the KCRC decided to consolidate its operations and in 1992 appointed Arup as civil/structural/geotechnical engineer for a new headquarters building at the southern end of the maintenance centre site. Construction of this eight-storey office building and three-storey annex for staff recreational facilities commenced in late 1992 and was completed in late 1994 (Fig 7).

For the new Ma On Shan line, the KCRC identified three out of eight station sites along the route for future topside residential development. In 2002, it appointed Arup for the full civil and structural engineering design of all enabling works above and adjacent to the new stations to allow for these future developments. The sites include Wu Kai Sha station, Tai Wai station, and Tai Wai maintenance centre, and the enabling works involved detailed design of all foundations, substructures, depot structures, and PTI structures (Fig 8). Arup had already been appointed for the design of the maintenance centre and the PTIs at Wu Kai Sha and Tai Wai.
The enabling works included capped columns stubs with couplers above the roof decks as a convenient means of building the future topside columns. All enabling works were completed in December 2004 ready for the opening of MOS Rail.

6. The Metropolis development alongside Hung Hom station.

7. KCRC headquarters building at Fo Tan.

2002-2007

The KCRC appointed Arup in 2002 as civil/structural engineering consultant to the lead masterplanning architect for station topside residential developments at Tai Wai maintenance centre (see pp55-61), Tai Wai station, and Che Kung Temple station (MOS Rail); Dairy farm/bus terminus/Fo Tan station and freightyard topside development (East Rail); Mass Transportation Centre (East Rail: Hung Hom station); and Tsuen Wan West station (sites TW5, TW6 and TW7), Yuen Long station, and Pat Heung maintenance centre (West Rail).

Arup also assisted the KCRC and its lead architect prepare control documents ready to call for tenders from developers to form joint ventures with the KCRC.

In 2003, Sino Land Properties and the KCRC appointed Arup as civil/structural/geotechnical consultant for the detailed design of the foundation and elevated deck to support ten 45-storey residential towers in the remaining undeveloped site A at Ho Tung Lau maintenance centre. This contains the track fan leading from the maintenance and stabling tracks to the main line connection, and so piled foundations had to be constructed next to live tracks. To meet this challenge Arup introduced an innovative high-strength minipile foundation system, with custom-made light drilling rigs that controlled adjacent track settlement and kept within the electrical clearances to existing overhead traction power cables demanded by the KCRC to meet its stringent safety requirements. The foundation works to support tower blocks were completed in spring 2006 (Fig 9).

Careful consideration has also been required in the design of the podium deck structure, in order to cater for the contractor's construction method above the extensive array of overhead catenary wires and supports. Launching the steel and precast podium deck structural elements was carried out at night under isolation and possession of live tracks. The project is planned to be completed by the end of 2007.

In August 2005, the KCRC appointed Arup as civil/structural/geotechnical consultant for the expansion and improvement of Citylink Plaza, a commercial building built above Shatin station in the early 1980s. New structure will be needed above the existing station platforms and part of the existing freightyard area next to the station, where normal day-to-day operations must be maintained. Foundation construction alongside live tracks and within station platforms will be a challenge for this busy commuter station. Construction is anticipated to start by the end of 2007.

With the newly operating West Rail and MOS Rail, there is the opportunity to generate at least 15 potential topside property developments adjacent to and above the stations - potentially nearly 4Mm^2 of development. Most of this will call for joint venture tendering up to 2008. Arup's extensive engineering design experience for railway topside development and its long working relationship with the KCRC bodes well for future involvement in these projects.

8. Interior of Tai Wai station PTI.

9. Minipile foundations being placed near live rails at the Ho Tung Lau maintenance centre site A.

Berny Ng is a Director of Arup in Hong Kong. He has been Project Manager for several of the KCRC station topside residential developments.

1. East Rail and its Arup projects in the context of the Kowloon/New Territories railway system.

2. Aerial view of Long Valley during construction of the Lok Ma Chau spur line. At the foot is the TBM launch shaft at Sheung Shui; in the distance, the excavation for the Kwu Tung station enabling works.

Consultants and contractors

Client: Kowloon-Canton Railway Corporation
except where otherwise stated

Detailed design contract HDD300
HCC300: East Tsim Sha Tsui station and elevated decks (pp5-17)

Lead consultant and all engineering design: Arup
Subconsultants to Arup - *Initial station planning:* David Thomas (formerly director, Arup Associates) *Station architect:* Rocco Design Ltd *Landscape architect:* Urbis Ltd *Signal Hill subway civil design:* Charles Haswell & Partners Ltd Main contractor for station and elevated decks (HCC300): Gammon-Nishimatsu Joint Venture.

HCC302: Pedestrian subways for East Tsim Sha Tsui station (pp18-24)

Lead consultant and all engineering design: Arup
Subconsultants to Arup - *Architect:* Rocco Design Ltd *Landscape architect:* Urbis Ltd Main contractor (HCC302 and subway content of HCC300): Gammon-Nishimatsu Joint Venture.

HCC301: Tsim Sha Tsui extension railway tunnel (pp25-31)

Lead consultant, architect, and all engineering design: Arup
Subconsultants to Arup – Hung Hom ventilation building architectural scheme design: David Thomas (formerly Director, Arup Associates) *Landscape architect:* Urbis Ltd
Main contractor (HCC301): Gammon Skanska Ltd.

MOS Rail system-wide fire safety strategy (pp40-42)

Fire engineering design: Arup

KSL100: Kowloon Southern Link Feasibility Study (pp43-47)

Lead consultant, engineering, and environmental design: Arup Subconsultants to Arup – *Architect:* Terry Farrell & Partners *Landscape architect and urban planner:* Urbis Ltd *Property consultant:* Insignia Brooke (Hong Kong) Ltd *Quantity surveyor:* Widnell Ltd *Land contamination/ecology:* Environmental Management Ltd *Railway systems:* DE-Consult *Financial consultant:* JP Morgan

LDB201: Lok Ma Chau spur line tunnels (pp48-54)

Promoter: Kowloon-Canton Railway Corporation
Client: Dragages (HK) Joint Venture Engineering and architectural designer to contractor: Arup Main contractor: Dragages (HK) Joint Venture

Tai Wai maintenance centre (pp55-61)

Lead consultant and all engineering design: Arup
Subconsultants to Arup - *Architect:* Aedas (formerly LPT Architects Ltd) *Quantity surveyor:* Davis Langdon & Seah Hong Kong Ltd *Landscape architect:* Urbis Ltd *Depot equipment:* Data Crystal Ltd Main contractor: Gammon Construction Ltd

Illustrations

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1. The tunnel boring machine *Mulan*, which drove the twin tunnels of the Lok Ma Chau spur line.

1.

ARUP

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To celebrate its 60th anniversary in 2006, Arup partnered with the international charity WaterAid in the Arup Cause initiative, which focused Arup's mission to "shape a better world" on the provision of safe domestic water, sanitation, and hygiene education to the world's poorest people.


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Illustrations: 1. New Hung Hom ventilation building, above the eastern end of the Tsim Sha Tsui extension tunnel; 2. Emergency communication point at East Tsim Sha Tsui station; 3. Sun Tuen Mun Centre development above light rail maintenance centre, North West New Territories; 4. Bored tunnel for the Lok Ma Chau spur line; 5. The 44m red brick/granite KCRC clocktower, completed in 1921 on Tsim Sha Tsui's southern shore: the only part remaining of the original Kowloon terminus; 6. Trading area on MOS Rail station concourse, using the "cabin concept" for fire safety; 7. Cantilevered viewing platform on the harbour side of the Salisbury Road access bridge to Wing On Plaza garden; 8. Trains being serviced at Tai Wai maintenance centre; 9. Vent structure at Wing On Plaza garden serving the public transport interchange beneath.

Front cover: The east approach to the Lok Ma Chau spur line tunnels. The train on the left is descending into the westbound tunnel towards the new Lok Ma Chau terminus. The train on the right is emerging from the eastbound tunnel, *en route* to East Sha Tsim Shui station. In the background is a new 55m footbridge which was craned into position under a night time track possession.

Inside front cover: The reprovisioned Middle Road children's playground at elevated deck level over East Tsim Sha Tsui station.

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