



“Interest in the renewal of and restoration of public transport is world-wide with the opinion that rail is the most effective method of moving large numbers of people speedily and efficiently.

“Melbourne has long been acknowledged as having one of the most extensive commuter rail systems in the world compared to other cities of similar size. However, by the early 1960s it was evident that the existing city terminals in Melbourne were heavily overcrowded and failing to accommodate the transport needs of the growing central business district.

“The construction of the Underground Rail Loop, undoubtedly one of Australia’s major engineering achievements, provided three additional city terminals servicing the entire activity centre. Commuters can now travel to five central stations, all located within easy walking distance of offices, shops and community facilities.

“The dual underground and surface rail system provides a bi-directional operation catering for peak hour traffic demands and an inter-modal choice of travel between train and tram services.

“Bi-directional operation of the dual rail service alleviates train movement difficulties at Flinders Street and further enhances the capacity and efficiency of the rail system.”

K P Shea
Managing Director
Metropolitan Transit Authority

HISTORY OF MELBOURNE'S METROPOLITAN RAIL SYSTEM AND THE ADOPTION OF THE UNDERGROUND RAIL LOOP CONCEPT

In 1839 the Victorian Government Surveyor, Robert Hoddle, planned a railway from Melbourne to Sandridge, now Port Melbourne. In 1854 the Melbourne & Hobson's Bay Railway Company opened such a line, which was quickly followed by the opening of many more privately sponsored suburban lines. By 1878 most of these lines had been taken over by the Government and during the land boom years of 1881-1891 they were extended with little regard for economics.

By 1891 the rail network closely resembled the system operating today, and no further construction was undertaken for several decades.

Because of this early development Melbourne had a most comprehensive rail network at the turn of the century, radiating from the city and favouring the beaches in the south and wooded hills in the east.

Electrification of the system, completed in 1926, added further to capacity and gave Melbourne a railway system unequalled by many cities even today.

In the early post-World War 2 years, rapid growth in housing and population occurred in outer suburbs, greatly increasing the demands on the system, although growth patterns were influenced by factors such as the introduction of television and the growth of private car ownership. To maintain services it became necessary to increase track and rolling stock utilisation through combinations of the following: more double lines or additional passing loops; improved signalling; more trains; and improved electricity supply.

Because the system is radial in nature, improvements in route capacity soon overtook the ability of the two central terminals to handle both passengers and trains. The problem was exacerbated by the fact that most passengers reside in southern and eastern suburbs, overloading one of the city terminal stations more than the other.

The Flinders Street/Princes Bridge station complex was handling some eight times the passenger volume of Spencer Street, while the number of eastern and southern suburbs arrivals and departures at peak periods was three times the number required to serve the northern and western suburbs – because of this imbalance many trains had to reverse from Flinders Street/Princes Bridge platforms to stabling sidings in Jolimont Yard, in the face of oncoming trains. The safe signalling procedures needed to carry out these movements greatly limited the capacity of each platform face.

It was predicted that by 1985, it would be impossible to handle the projected 180 morning peak hour train arrivals at Flinders Street/Princes Bridge stations.

Solutions to the central problem

Criteria for the solution to the problems inherent in the city's imbalanced radial system were: provision for traffic flows beyond Flinders Street Station to new stations closer to passenger destinations in the Central Business District; improved flow of trains at Flinders Street by eliminating or reducing train reversing movements; provision of direct access to both existing and proposed new city stations from as many lines as possible; operation of each line or groups of lines as independent systems; integration of the city terminal system.

The solution settled upon was the present underground loop system, which permits trains to enter, continue through and exit from four complementary loop systems mostly below the city centre, giving passengers convenient access to a number of strategically placed terminals.

PROJECT SCOPE

The \$500 million underground loop project involved the construction of four single-track tunnels (13 kilometres total length) along the north and east sides of the Central Business District, three underground stations and an additional two-track viaduct between Spencer Street and Flinders Street stations.

The undertaking was one of the largest in Melbourne's history. It involved major contributions from several hundred people in both the private and government sectors – led by professional engineers.

Each loop tunnel is dedicated to a group of suburban lines and is independent with no cross connections between loops.

The unusual design of two-over-two tunnels was adopted to enable the tunnels to be built wherever possible within the width of city streets and construction methods were devised to cause the least surface movement.

Considerable attention was paid to limiting disruption to existing rail services and to minimising inconvenience to pedestrians, road users and building occupants through the minimum closure of roads.

The new stations were located to suit known and forecast passenger destinations around the CBD with Museum Station designed for the greatest demand. All stations have two centre platforms one above the other joined by escalators and stairs to subsurface concourses and booking halls. Upper platforms have been kept as close to the surface as possible.

FACTS AT A GLANCE

TUNNELS

- Four separate tunnels progressively brought into service January 1981-April 1985	
- Total length of driven tunnels	10 km
- Total length of cut and cover tunnels	3 km
- Total length of approach ramps	2 km
- Volume excavated (80% by mechanical methods)	900,000 m ³
- Volume of concrete placed	300,000 m ³

UNDERGROUND STATIONS

- Platform length for 6-car train set	160 m
- Platform width	3.5 m
- Design interval between peak hour trains	2.5 mins

MUSEUM STATION

- Progressively brought into service January 1981 to April 1982	
- 5 levels	
- Maximum depth (Excavation by open cut)	29 m
- Number of escalators	21

PARLIAMENT STATION

- Progressively brought into service January 1983 to April 1984	
- 4 levels	
- Maximum depth (Excavation by mining methods)	40 m
- Number of escalators	13

FLAGSTAFF STATION

- Brought into service May 1985	
- 4 levels	
- Maximum depth (Excavation by mining methods)	32 m
- Number of escalators	14

FLINDERS-SPENCER STREET VIADUCT

- Brought into service December 1978	
- Total length	722 m
- Length of spans	30 m (35 m max)
- Weight of beams	290 tonnes max
- Type of construction	Precast concrete box girder

APPLICANT DETAILS

APPLICANT:	The Connell Consortium (John Connell and Associates; Mott Hay and Anderson, UK; Hatch Associates, Canada; Jacobs Associates, USA.)
	TOGETHER WITH
	MetRail (Rail Division of the MTA)

CLIENT:	Metropolitan Transit Authority of Victoria (as successor to the Melbourne Underground Rail Loop Authority)
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ROLE OF THE APPLICANT:

When presenting the enabling legislation for the Underground Rail Loop to Parliament, the Minister for Transport stated that the client (MTA, formerly MURLA) would employ only a small staff and would make use of consultants and contractors.

To cover the wide range of engineering disciplines involved and the managerial and administrative tasks without a large staff, the client gathered a small team of executive engineers and architects to review the activities of the consultants.

After careful analysis of the consulting services required and review of proposals from a wide range of engineering consultants, the client selected The Connell Consortium to act as principal consultant. The Consortium offered a strong Melbourne-based office with specific, directly relevant overseas expertise that would be relocated to the Melbourne project office.

MetRail was selected as consultant for works on railway property largely because of the inevitable inter-relationship of railway operations and new works in these areas.

The Connell Consortium prepared a pre-design report for the total project and subsequently was appointed principal consultant for the design and supervision of the works (other than those in the existing railway yards, the overhead traction system and the signalling and communications). In addition, the Consortium provided management services for the whole project.

MetRail was responsible for design and construction by day labour forces of the works in the existing railway yards, the overhead traction power system and the trackside signalling and communications equipment.

The Connell Consortium and MetRail combined in a task force to design and supervise the development, design, installation and commissioning of a computer-based centralised train control and management system for the loop at METROL, the Metropolitan Train Control Centre.

ROLE OF OTHER CONSULTANTS:

Several sub-consultants were engaged for specialist advice. The following were appointed for the architectural finishes of stations and for the booking halls:

Parliament Station

Architect: McIntyre Partnership Pty Ltd

Quantity Surveyor: W T Partnership

Museum Station

Architect: Perrott Lyon Mathieson Pty Ltd

Quantity Surveyor: Rider Hunt and Partners

Flagstaff Station

Architect: Stephenson and Turner

Quantity Surveyor: Cameron and Middleton Australia Pty Ltd

CONSTRUCTION CONTRACTORS:

Over 300 contracts were entered into, ranging from \$50 million to less than \$500 in value. Contractors were predominantly Australian companies but an Italian/Australian company was responsible for a significant portion of the excavation and lining of driven tunnels and stations. Government utility services departments and Melbourne City Council were involved in substantial services diversions.

ROLE OF THE CONNELL CONSORTIUM AND METRAIL

Engineering Achievements

At least twenty technical papers on various engineering aspects of the Loop have been presented at national and international conferences and each has been acknowledged as a significant contribution to the knowledge and experience reservoir of Australian engineers.

A small selection of engineering achievements is included in this document to illustrate the wide range of disciplines involved in the project and to demonstrate the calibre of the engineering involved.

Technology Highlights

The design and construction of the Loop incorporated many features which were Australian “firsts” or were at the forefront of technology. For example:

- First use of road-header excavating machines in civil engineering construction.
- First use of shaft raise-boring for large scale civil engineering construction.
- First systematic use of shotcrete for ground control at the cutting head of a tunnel boring machine.
- Earliest known application of several New Austrian Tunnelling Method (NATM) techniques using rockbolts and shotcrete for tunnel support, together with in situ stress/strain measurements.
- Use of finite element design methods, combined with systematic ground monitoring (both surface and underground), to enable the designs of primary ground support and final lining to be refined with consequential savings in cost and improvements to progress.
- Development of a retrievable test rig (in collaboration with Monash University) to evaluate the capacity of large diameter pile rock sockets.
- Research world-wide and development of techniques to predict and control stray electrical currents from the train traction power system passing through adjacent structures and causing gradual structural degradation.
- First provision to stop and start escalators while carrying passengers. Not previously accepted by the Department of Employment and Industrial Affairs, this facility is intended for use in emergencies and utilises thyristor motor drives for full speed variability.
- Design of the southern hemisphere’s longest heavy duty escalators at Parliament Station.
- Research and development of a unique acoustic treatment of tunnels using mineral fibre, encapsulated in metal “pods”.
- Development of the world’s largest computer-based train control and management system.
- First application of colour visual display units for passenger information displays at railway stations.

ENGINEERING ACHIEVEMENT

EXAMPLE 1 – TUNNELLING WITH MINIMUM DISRUPTION

The excavation and lining of 10 kilometres of 7-metre external diameter tunnel in the Central Business District of Melbourne presented challenging design tasks and construction logistics.

The route selected takes the tunnels within influence of historic buildings including the Old Treasury, Parliament House, Princess Theatre, the Magistrates Court, Museum of Victoria and the Royal Mint. In addition, “sensitive” buildings such as two hotels, several expensive apartment buildings, Royal Melbourne Institute of Technology and the State Film Centre are nearby.

Client requirements

- Tunnel construction was to have as little impact as possible on city buildings and on building occupants.
- The risk of surface settlement was to be minimised.
- The environmental status of the city was to be respected by controlling noise and vibration to meet new standards still in draft form at that stage.
- Rapid progress and bulk excavation methods were to be encouraged to achieve early completion and cost savings.

Planning and implementation initiatives

- To keep the four tunnels generally within road reserves and away from buildings a paired two-over-two tunnel configuration was adopted. Tunnel excavation sequence design and lining proposals were developed using finite element design theory to predict the performance of rock pillars between tunnels and the total rock stress patterns around the tunnel group. This process was complicated where tunnel alignment dictated the configuration and reduced rock pillars locally to 2.5 metres thickness. The notorious variability of the geology around the city perimeter also had to be taken into account.
- Several test shafts were drilled beyond the lowest tunnels to allow visual inspections by designers and sampling of in situ rock. Pilot tunnels, excavated so that they could later be incorporated into permanent works, provided valuable test data on ground behaviour using the proposed primary support methods. These additions to the existing wealth of core-drilled samples provided valuable design data.

- Excavation by blasting was excluded wherever possible to preserve the integrity of the rock around the tunnels and to avoid noise and vibration during construction. It was recognised that a new method of excavation would be required so a world-wide study was made and a full-scale trial was conducted to confirm the practicality of using “road header” excavating machines for this scale of work in Melbourne ground. Contractors subsequently embraced this concept and five road headers were used on the project.
- A primary ground support system was designed for application within one metre of the freshly excavated tunnel face. This involved pioneering the use of “shotcrete”, including production methods, quality control and safety. The design controlled the relaxation of the rock around the tunnels and maintained the integrity of the rock pillars between tunnels. This system was proven in a full-scale pilot tunnel prior to completing specifications.
- During construction, the movements of the excavated tunnels and surface subsidence above were monitored precisely to confirm the predictions made of the performance of primary support and rock stresses. This enabled savings to be made, where ground conditions permitted, by reducing the amount of primary support during excavation and by minimising the extent of reinforcement in the final tunnel linings.

FEATURES

Excavation and lining of the tunnels was achieved on a 24-hour shift work basis over a period of several years, with virtually no fuss or “headlines”, which is usually indicative of success.

- There was no significant surface settlement.
- There were no proven claims of damage to buildings adjacent to the tunnels.
- There was minimal public complaint about noise and vibration and no injunctions were lodged at any stage.
- The specifications attracted competitive tenders.
- Actual Costs and Progress were comparable with similar projects world-wide.
- All contracts were settled satisfactorily without need for arbitration or litigation.

ENGINEERING ACHIEVEMENT

EXAMPLE 2 – CONSTRUCTION AMONGST OPERATING RAILWAY TRACKS

To connect the existing suburban rail system to the underground works, some 5 kilometres of reinforced concrete ramps and box section tunnels were constructed on railway property in the Jolimont railyards area and in the Spencer Street and North Melbourne areas.

These locations combined several of the most difficult features encountered in engineering construction:

- The ground conditions were difficult and ranged from hard fresh rock to basalt floaters in weathered clay, to running sand.
- Access was difficult being adjacent to operating railway tracks and in some cases crossing operating tracks with attendant safety precautions and disruption.
- The works required movement of existing railway tracks to create each work-site. This entailed pre-planning of night and weekend moves of trackwork, overhead traction power lines and complex signalling equipment, all to stringent safety requirements.

FEATURES

- The design of the ramps and tunnels was arranged to permit construction in multiple stages. It was complicated further to allow for the placement and removal of heavy steel strutting for excavation, which was necessary to accommodate large ground loads and the impact of adjacent train movements. Special attention was paid to design detailing and construction, to cope with the ever-present problems of aggressive ground water and limits on seepage into tunnels.
- There were no significant railway accidents or incidents throughout several years of high-risk construction operations.

- In the Jolimont yards where train movements are virtually continuous, steady progress was achieved using a combination of day labour forces and contractors. The schedule was arranged to provide concurrent access for contractors fitting out the running tunnels through to Parliament and Museum stations including delivery of long lengths of welded rail.
- Where the Northern Loop passes Festival Hall and crosses under Dudley Street, design and construction satisfied the following challenges:
 1. No subsidence or damage to Festival Hall.
 2. No interference with performances at Festival Hall.
 3. Diversion of major utility services mains including large diameter sewerage, water and high pressure gas lines which required secure temporary support during construction.
 4. Support of the adjacent main line track by temporary works, including underpinning of the Dudley Street bridge, to carry vital standard gauge trains to New South Wales.
 5. The crossing of Dudley Street, one of Melbourne's busiest transport arteries, requiring careful pre-planning and execution of staged traffic movements.

ENGINEERING ACHIEVEMENT

EXAMPLE 3: INNOVATIVE DESIGN AND CONSTRUCTION METHOD – FLAGSTAFF STATION

An innovative method was adopted for the construction of Flagstaff Station taking account of the peculiar geological “sandwich” structure of the area, comprising partially weathered but reasonably competent basalt in the arch area, with soft weathered Silurian mudstone bedrock in the lower half. Between these two layers was a soft deposit of “Werribee Sand” several metres thick.

After the awarding of contract, the design engineers collaborated with the contractor to produce a unique approach for constructing the large station chambers in this difficult “mixed ground” situation.

At each of the two levels (arch springline and station foundations) drifts were excavated along each corner of each of the two station chambers. The next step was to “raise-bore” a total of 228 one-metre diameter shafts at three-metre centres along each of the four parallel station walls, connecting the top and bottom drifts.

These shafts were progressively concreted followed by the drifts to form a permanent reinforced concrete “skeleton” for each station chamber.

The arch of the chamber was then excavated and concreted, followed by bulk excavation of the materials below. During bulk excavation, as the “raise-bored” columns were exposed, temporary cross struts were installed until the station’s permanent structural elements were completed.

FEATURES

The use of this method enabled approximately \$1 million (1975 values) to be saved on the original contract price and the structure was created in a safe and predictable manner with minimal surface subsidence, illustrating the benefits that can flow from creative co-operation between design and construction engineers.

ENGINEERING ACHIEVEMENT

EXAMPLE 4 – CONTROL OF LARGE EXCAVATION – MUSEUM STATION

Museum Station was constructed by the 'cut and cover' method, the main excavation being 168 metres long by 22.5 metres wide and varying in depth from 29 metres at Swanston Street to 22 metres at Elizabeth Street.

Excavation methods and the temporary steel support for such a large excavation in a major city street required extensive site investigation coupled with careful planning and design. The design of the major temporary support, except for detailing of connections, was undertaken by the Connell Consortium and the steel was pre-ordered so that the fabrication of temporary support could start soon after the award of the contract.

The temporary support structure comprised seven levels of struts in the eastern half of the excavation and six levels in the western half. Struts were located clear of the concrete structure to minimise interference with the contractor's chosen construction methods. Generally, each main strut supported two soldier piles on each side of the station, transferring the load to the struts through 'V'-shaped strut ends.

The 'V'-shaped strut ends were pre-assembled, lifted into place and welded to their respective piles. Each main strut was then lifted into position and the connections bolted. At the north end, the gap between the bearing plates of the main strut and the 'V'-shaped strut was filled with a liquid epoxy mortar.

At the south end of the main strut a 200mm gap was left between the bearing plates into which an 800 tonne jack was placed for pre-loading the member. Following this, epoxy concrete blocks were cast on each side of the jack and after curing the jack was removed.

FEATURES

The use of epoxy mortar and concrete jointly developed by the contractor and the consultant proved to be a practical solution to the problem of ensuring that high loads were transmitted evenly over large bearing surfaces.

All steelwork for the temporary system was fabricated off-site. The quantity (2600 tonnes) of steel and the standardisation of members allowed the fabrication sub-contractor to plan for economy and fast production.

As the struts were subjected to high loads by the rock there was negligible opportunity for expansion and so, to prevent buckling, it was necessary to cool the strutting with water sprays on sunny days when air temperatures were over 25°C.

The sequence of excavation and strut installation was carefully controlled. To ensure that the entire support system functioned as designed, an elaborate monitoring system was installed to record temperature, by means of thermocouples and normal gauge thermometers, and loading, by means of mechanical and electrical strain gauges.

The excavation, installation and removal of the temporary support and construction of the station structure were all completed without significant movement of the adjacent ground and without effect on adjacent buildings.

ENGINEERING ACHIEVEMENT EXAMPLE 5 – PARLIAMENT STATION – A NEAT ENGINEERING SOLUTION

The design and construction of a major underground station in the historic Parliament House precinct and at the junction of major city streets presented numerous challenges.

Parliament Station is “sandwiched” between Parliament House, The Windsor Hotel, The Princess Theatre and two multi-storey residential apartment blocks. It is located under the junction of Bourke, Spring and Nicholson Streets – major arteries into the Central Business District.

Preservation of the historic precinct

The solutions to some of the challenges which arose required painstaking attention to detail.

- The historic Parliament House fence was recorded by photogrammetry prior to being carefully dismantled and stored. It was subsequently re-erected, accurate in every detail, using the photographic record as a blueprint.
- The Bourke Street entrance to the South Booking Hall was discreetly planned to ensure minimum impact on the National Trust classified Windsor Hotel.
- The huge and very old Magnolia Grandiflora in the Parliament House garden was prepared and relocated over two winter seasons with a combination of horticultural and heavy lift rigging skills.

Innovative design and construction

The excavation and support of the series of large caverns which form the station called for innovative construction methods backed by comprehensive design verification and site supervision.

- The geometric configuration of the elliptically-shaped side-by-side platform tunnels with the escalator and concourse tunnels between, left a pillar of rock which was too narrow to cope with the imposed stresses, particularly when part of the pillar was removed for cross passages between platforms.

The solution was to replace rock with concrete. The engineering achievement was to blend design and construction expertise to enable the pillars, or “filler walls”, to be constructed ahead of the main tunnel excavation. This was managed by excavating a tunnel just big enough to construct the filler walls. As the main tunnels were excavated each side, the primary steel supports were landed directly onto the prepared “filler walls”. By using a controlled sequence of tunnelling and careful attention to the maintenance of the ground support as the overlapping tunnels advanced, minimal surface settlement occurred, a significant achievement given the size of the voids created beneath.

- The South Booking Hall at Parliament Station is directly under Spring Street in a heavily trafficked area. To minimise disruption to the public, the booking hall was constructed upside down. In essence the roof of the hall was constructed first, at ground level in a series of partial road closures, then the time-consuming excavation was carried out underneath while traffic continued overhead. This required the foundations and columns for the roof structure to be constructed in advance and this was achieved by accurately augering piles on the required column grid and belling them out to form foundations at predetermined horizons. High quality “flowing” concrete was used to cope with the tight access to the foundations from the limited worksites in the roadway.

Attention to design details and careful site supervision enabled these piles to be exposed as column supports to the booking hall roof as excavation proceeded. Scalloped wall excavation between the perimeter piles combined with “shotcrete”, created the permanent walls of the booking halls as arches between each pile. This cost-effective technique enabled rapid excavation to proceed concurrently with wall construction.

ENGINEERING ACHIEVEMENT

EXAMPLE 6 – SAFETY FEATURES INCORPORATED IN THE DESIGN

It was recognised from the outset by client and consultant that an underground railway presents special risk situations by virtue of the environment and the large numbers of vehicles and passengers using the facilities. As a result, the design of the installations has at all times reflected the need to avoid the incorporation of materials, equipment or features which could cause hazardous situations in tunnels, underground stations and other parts of the system.

A joint committee with a specific brief to identify potential hazards and risks continually reviewed designs and operating procedures. The committee studied reports of overseas railway accidents and submitted recommendations for improvements to loop designs throughout the project. It also arranged simulated emergency situations in the tunnels during final testing and commissioning to confirm the viability of access, communications and other facilities.

Avoidance of Hazards

- **Tunnel clearances:** Clearances were designed for future train types and dimensions were fixed after a full scale mock-up was prepared for various cant and curves. Allowance has been made for refuges and full-tunnel length walkways at a level too low to encourage passengers to leave the train but high enough to step down.
- **Safety signalling:** Full interlocking of railway points and signals is incorporated and the computer-based Train Describer enables controllers to trace the movement of all trains in the loop.
- **Train radio:** A leaky coaxial cable has been provided through the tunnels to facilitate communication between train drivers and the train control centre (Metrol) at all times.
- **Underground station platforms:** The platform edge tiles are of contrasting colour and texture to assist poorly sighted people. Tiles are laid on an insulating bed to avoid any remote possibility of electric shock to passengers boarding a train during a fault situation.

Non-flammable materials and minimisation of smoke and toxic fumes

- **Architectural finishes:** Most materials are non-flammable such as tiles, plaster, metal panels, etc. Frames for partition walls are metal and timber for feature panelling is treated with a fire retarder. Any plastics chosen have low flammability and do not emit dense smoke or toxic gas.
- **Electric cables:** There are large quantities of cables throughout the tunnels and stations so particular care was taken over cable specifications. Conventional cable insulation such as PVC generates HCL gas when burnt and would be a major hazard. All available cable types were tested to identify those with fire resistant properties and low fume and smoke emission.

Specific cable types were nominated for 240V, 415V, 1000V and 1500V power distribution cables, as well as signalling cables, telephone data link cables and composite data cables for audio and video channels. Additional duct protection was specified for signalling and communications cables to ensure that vital data could still be transmitted to Metrol in the event of fire in the tunnel.

Security of lighting and power systems

The design approach to lighting and power supplies has been to ensure sufficient power is available to essential services for safe evacuation of passengers from tunnels and stations in the event of a total emergency.

- **Lighting:** To ensure lighting at all times, vapour-proof fluorescent lights on each side of the tunnel are on separate circuits and alternate lights are on different phases of the three-phase supply. In the event of power failure one supply becomes automatically connected to a battery-operated uninterruptible power system (UPS) until standby generators start up and take

over. In the unlikely event that all tunnel power cables are destroyed, then each third light over the walkway will operate with its own inbuilt battery for a reasonable period. Station circuits are divided and 10% of total station lighting is connected to the uninterruptible supply system.

- **Power supply:** Power is supplied through five separate substations around the loop each with dual feeders. At each underground station a standby gas turbine generator and uninterruptible battery supply is provided. Each substation has UPS supply to maintain signalling and communications. Special installations such as fans and pumps have two separate power supplies via different tunnels with automatic changeover.
- **Standby power:** Gas turbine generators are located at each station and Metrol. The failure of one HT feeder automatically activates the generator which accepts the load. If two HT feeders fail, a load-shedding system ensures that the generator is not overloaded. Battery-powered uninterruptible power systems at stations, Metrol and major substations supply essential communication signalling and lighting. Battery capacity at stations will maintain essential lighting in tunnels and stations for up to 2 hours.

Ventilation systems

Air handling units and draught relief shafts are provided at each station and four major fan installations are provided around the loop. Apart from their essential cooling role, the tunnel fans have a vital emergency role for control of heat and smoke. Where ventilation shafts enter the tunnels, remotely controlled dampers have been provided to control air flow to and from each tunnel. The fans can be operated in supply or extract mode to assist prevailing tunnel air flows which vary according to ambient conditions. Air flow sensors have been installed to allow Metrol to remotely operate the fans using air flow data as a guide.

Protection against flooding

All entrance points to the loop have been constructed above potential flood water levels corresponding with storms more severe than any recorded to date. To cope with seepage and large flows from fire fighting or burst mains, multiple pump installations with dual and standby power sources have been located around the loop tunnels.

Fire protection systems

- **Tunnels:** 100mm mains have been installed along the walkway side of tunnels with hydrants at 60 metre intervals. Several ring main connections to the city supply have been made and flow meters installed to identify sections of tunnel where a flow has occurred, using data communication lines to Metrol.
- **Stations:** As a major contribution to the safety and security of each station, automatic sprinklers were incorporated. In areas containing vital equipment which is susceptible to water damage, automatic gas extinguishers have been installed and audible and visible alarms are triggered prior to release of gas. Fire extinguishers, hydrants, hoses and break-glass alarms have been provided throughout stations.

Control and Monitoring System (CMS)

A dual computer system at Metrol is dedicated to the supervision of electrical and mechanical equipment throughout the loop. Remote field stations send equipment status reports to Metrol on a routine scan and trigger alarms in the event of emergency. During normal operations, Station Controllers supervise equipment, but in an emergency Metrol can co-ordinate totally by the CMS system.

Emergency communications

- **Train radio:** Provision has been made for train drivers to communicate with Metrol throughout the loop once all trains are radio-equipped. In addition emergency telephones have been provided at 150 metre intervals in tunnels and flashing lights have been installed to alert drivers that Metrol wishes to make contact.
- **Emergency services radio:** Extensive tests have been carried out by fire, ambulance, police etc. to understand the limitations of their radio systems within the tunnels.
- **Emergency telephone services – DISPLAN:** Emergency communication pillars have been installed at surface entrances to the loop to allow each emergency service organisation to establish its own local communication command post. Telephone lines and DISPLAN lines are provided to each pillar.

ENGINEERING ACHIEVEMENT EXAMPLE 7 – LIFTS AND ESCALATORS

The vertical transportation system required for passengers at Museum Station was among the most demanding of all the new underground loop stations.

At full development, with 2½ minutes headway between trains, peak hour passenger flow at Museum Station is estimated at some 30,000. The effective vertical transportation of this passenger volume over a total height of 25 metres between street level, booking hall and platforms was a significant engineering task, requiring the provision of 21 escalators from 4.3 to 14.4 metres vertical rise.

In addition, three hydraulic lifts were included for incapacitated persons, MetRail staff and emergency uses. A schematic arrangement of these services is shown opposite.

In common with other stations, escalators were all of heavy duty design appropriate to continuous operation and high load factors. They were designed for a normal operating speed of 45 m/min, at which speed they each have a nominal maximum capacity of 8,000-10,000 passengers per hour.

In an emergency, it may be necessary by remote control to start up or reverse escalators at short notice from the deep platforms at Parliament and Flagstaff stations. This means being able to stop and start escalators carrying people after announcements and alarms – a feature not previously allowed by the Department of Employment and Industrial Affairs.

To prove the feasibility and safety of this proposal, two 14.4 metre-rise escalators at Museum Station were fitted with thyristor drives giving fully variable speed capability. After exhaustive tests, formal approval was gained, a world first.

The other 19 escalators are two-speed, with remote starting permissible in the unloaded condition, safeguarded by closed-circuit television surveillance and interlocked warning signs and voice announcement.

Variable speed escalators are also equipped with “speedray” devices to allow operation at 10% speed when empty, accelerating to full speed at the approach of a passenger, so conserving power and reducing maintenance.

Comprehensive safety features are fitted to all escalators.

As a result of the successful trials at Museum Station it was decided to install variable speed escalators between platform concourses and booking halls at both Parliament and Flagstaff Stations.

The installation procedures at these latter stations were complicated by the restricted access available. The design of the booking halls and declines and the sequence of construction were pre-planned to provide sufficient manoeuvring space for installation of large escalator components.

The longest heavy duty escalators in the Southern Hemisphere were installed at Parliament Station, and accordingly, special attention was required for all engineering features during design, construction and commissioning.

ENGINEERING ACHIEVEMENT

EXAMPLE 8 – ELECTRONIC CONTROL AND MANAGEMENT SYSTEMS

The advanced \$10 million computer-based Train Describer System controlling the movement of trains through the Underground Loop, is the largest system of its kind in the world.

The Melbourne Metropolitan Train Control Centre (METROL) houses computerised equipment which controls signalling for all trains in the inner city area.

When Metrol became fully operational in 1983, the system replaced five mechanical signal boxes located in the Flinders Street area, centralising control of the metropolitan rail system and greatly improved the overall efficiency of the rail service.

How the Train Describer System works

The running of trains is under the supervision of five Area Controllers each handling one of the five groups of metropolitan lines.

Each of the Area Controllers has a route control panel, a keyboard and five colour graphic visual display monitors. The graphic displays show the track layout, train description, train location and status of routes, track circuits and signals. The Controllers can pre-set train routes by activating signals remotely.

Four-digit train description numbers are keyed into the system manually by signalmen at fringe signal boxes for inbound trains and by Metrol Area Controllers for outbound trains coming into the system from the stabling yard. Train description numbers are then displayed on VDUs and the track diagram, moving in unison with the progress of each train through the system.

Metrol has brought the control of the inner rail system into one central building which is designed for expansion to other areas of the metropolitan network.

Control and monitoring of Electrical and mechanical services

Metrol also provides an important monitoring capability, keeping a constant watch on all facilities. For example, Metrol monitors underground stations' power, ventilation, escalator movements, all aspects of public security and safety and activates passenger information displays on platforms and concourses. This monitoring role contributes to control over threats to public safety such as fires, accidents and threats to public property such as vandalism.

A separate dual computer system collects and evaluates data transmitted from sensors around the loop and then provides information on display monitors at each underground station and at Metrol. This provides the means to check the condition of all facilities and to activate them remotely for changing conditions and for emergencies.

ENGINEERING ACHIEVEMENT

EXAMPLE 9 – FLINDERS STREET-SPENCER STREET VIADUCT

The provision of two new tracks between Flinders Street and Spencer Street stations completed a vital link in the Underground Rail Loop Project.

For most of the distance between the stations the new tracks are carried on a 722-metre long elevated structure to the south of the existing four-track viaduct. The route passes over five of the city's principal traffic arteries and entailed the diversion of a large number of buried services where foundations could not be designed to economically avoid the obstructions. These diversions were largely completed by Statutory Authorities and co-ordinated by the Connell Consortium to a critical timetable before overpass construction commenced.

The structure carries the main freight route and suburban rail traffic. Given the main line design load requirement, a relatively low unit structure weight was achieved by the adoption of 30-metre long precast prestressed concrete box beams, the largest of which is 35 metres long, each carrying a single rail track. A cantilever formed with the precast beam carries both a walkway and essential services.

Foundations are deep, large-diameter cased piles socketed into the sedimentary rock. These foundations had to be formed through overlying deposits of river silts and clay, and over part of the structure length, fill material within the old Port of Melbourne shipping swing basin. Under these deposits exist various series of gravels and clays above the Silurian sedimentary bedrock.

Most pile sockets were inspected visually to verify the foundation adequacy and a special down-the-hole test rig was developed to apply, hydraulically, a proof load to confirm the design parameters adopted for socket performance.

As the alignment follows the existing tracks for part of the route, curves had to be accommodated at each end. By adopting a single large precast box girder, both torsional strength and simplicity of construction were achieved.

The viaduct structure is located on the river side of the earlier rail overpass, forming a new backdrop to the river and a base line to the city. Accordingly, attention has been given to the aesthetics of the finished structure. Concrete surfaces of the piers are, in general, sand blast treated to provide a deep textured finish which contrasts the off-form precast box girder surfaces. High quality precasting techniques were used for the fascia panels forming the edge to the cantilever walkway.

ENGINEERING ACHIEVEMENT EXAMPLE 10 – ACOUSTIC PODS = QUIETER TUNNELS

In the past, an objectionable level of noise was accepted as normal for railways operating in confined spaces, but today, public transit authorities and designers make every effort to reduce noise levels and improve passenger comfort.

The source of railway noise is principally produced by the rolling contact of metal wheels on rails and the vibration set up in wheels and rails is radiated as airborne noise. This noise may be greatly accentuated by reverberation. The carriages act as partial barriers between passengers and the sound produced, but older rolling stock may operate with windows open. Carriages are then considerably less effective as noise barriers and it is important to concentrate on mitigating the noise by the use of sound-absorbing materials on structures.

Sprayed treatments to tunnel surfaces have been used with some success elsewhere in road and rail tunnels, but absorption coefficients revealed a deficiency at the frequencies associated with Melbourne rolling stock.

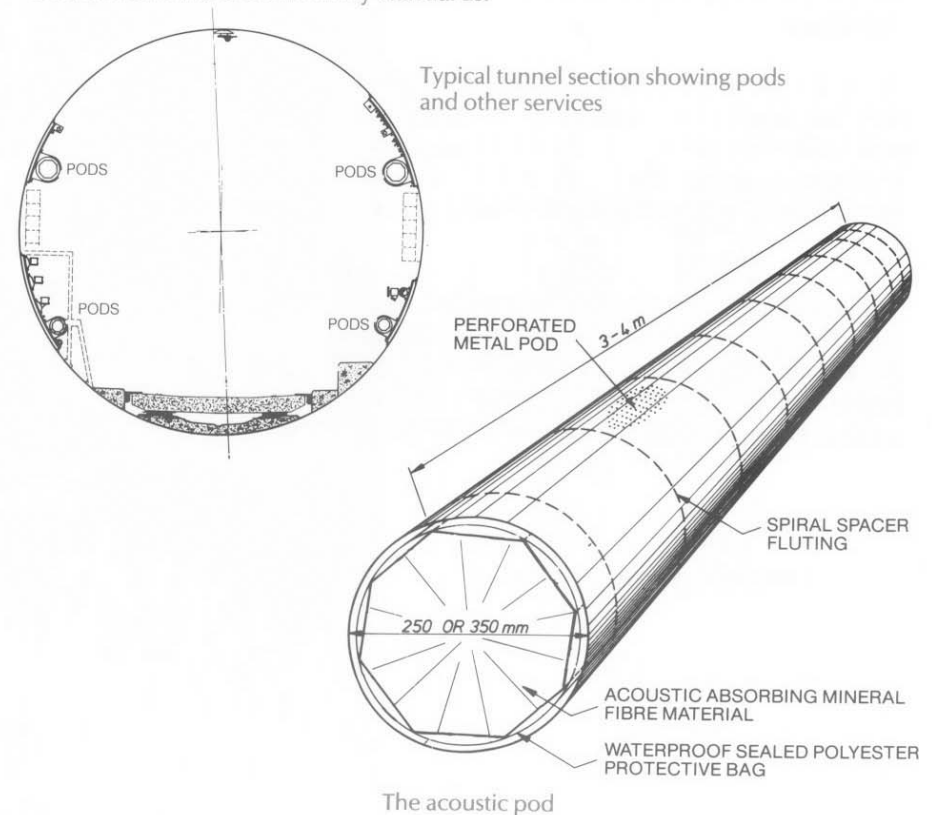
A “pod” system utilizing mineral fibre as the basic absorption material was developed which takes the form of cylindrical absorbers extending along the length of the tunnels. Sound energy fed into the space between the carriage and tunnel wall is eventually influenced by the presence of sound absorber pods on both sides of the tunnel.

The absorption system has been very effective, reducing noise inside carriages by some 9 dBA, thereby allowing easy conversation between passengers.

Apart from acoustic performance, in-service operation of tunnels dictated that there should be extremely low fire, smoke and carcinogenic risks associated with use of the pods, with the added requirement of robustness and washability. The final cylindrical form met all requirements with a high degree of success.

Ground-level openings appear at a number of locations throughout the loop as part of the draught relief shaft system. Buildings in the vicinity of openings include commercial and public buildings and residential premises and despite full acoustic treatment of the tunnel system, the noise level at draught relief openings also made it essential to incorporate sound treatment.

The unique acoustic treatment of the loop tunnels and draught relief systems has provided train crews, passengers and the general population of the City of Melbourne with an effective acoustic control system in keeping with current environmental and community standards.



ENGINEERING ACHIEVEMENT EXAMPLE 11 – MANAGING THE PROJECT

INTRODUCTION

The Connell Consortium was entrusted with the day-to-day management of the total project under the direction of the MTA (MURLA) General Manager and Director of Engineering and his supporting staff of executive engineers and architects.

In 1971, when the Consortium was appointed, the project consisted of four loops and three stations with reduced scope to meet the Government's funding constraints. The system was to be in service by late 1978.

Due to high inflation rates in the early seventies, the Government was forced to prolong the project to stay within planned cash flows. This necessitated a staged hand-over of facilities and created an environment where it was inevitable that the scope of the project would expand due to the following circumstances:

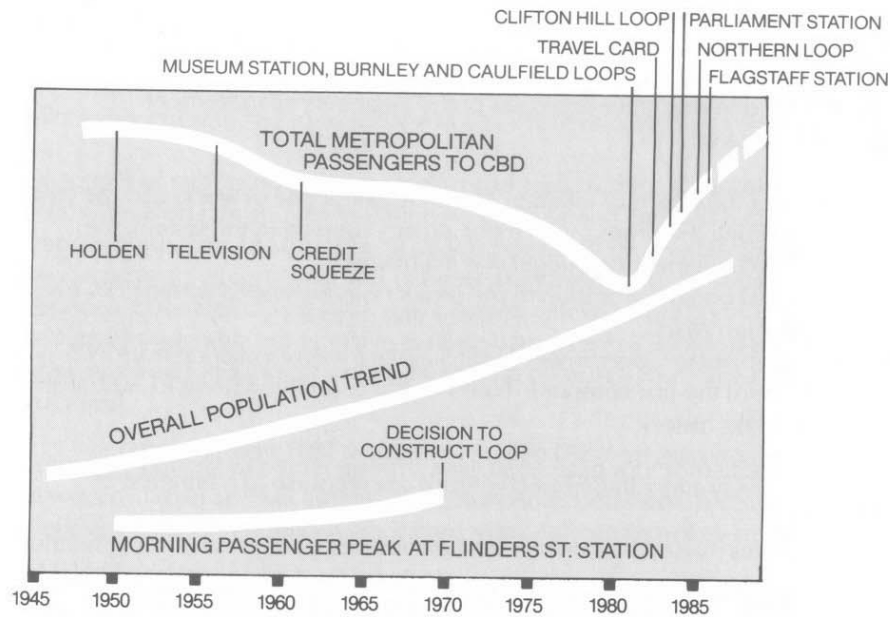
- User expectations demanded higher standard facilities.
- Enhancements were possible due to new technology.
- Experience from overseas metro systems highlighted the benefits of additional safety features and operational facilities.
- In the light of updated passenger forecasts and city developments, some station booking halls and entrances were expanded.

In this situation, the management task involved optimising the design to meet MTA requirements and regulating the cost and progress to achieve Government cash flow constraints in such a way that MTA had an up-to-date projection of the final project cost and timetable at all times.

FEATURES

Some of the demonstrative examples of the engineers' management achievements are:

- Taking out the effects of inflation, the increased scope of works and the costs of completing the project with trains already running in the system, the overall 1971 engineering budget was maintained.
- The annual budget allocation to the project was expended within $\pm 5\%$ every year over ten years.
- Accountability to Government Audit Standard was maintained from 1971 using one of the first computer-based cost accounting systems in Australian public works history.
- Over 300 contracts from \$50 million to less than \$500 were tendered competitively and administered without any recourse to arbitration or litigation.
- Full use was made of the computer-based critical path programming method when the technique was in its infancy in Australia. A vast number of variables were involved to co-ordinate both the design process and construction and the record shows that this was managed successfully.
- MTA (MURLA) sponsored a safety programme developed specifically for the project and modified as the project moved through the phases of heavy civil engineering, electrical and mechanical engineering and building works. All contractors participated in the programme but without affecting contractual, insurance or statutory requirements. Given the nature of the work and the confined underground workplace, the programme produced positive results in containing serious-injury accidents.



Patronage figures which affected the 1970 decision to construct the Melbourne Underground Loop and which have subsequently vindicated that decision.

Prior to 1970 trend curves indicated that the total number of passengers was declining due to numerous factors.

The numbers of peak hour commuters were increasing in line with population increase however, and this emphasised the inefficiency of the Flinders Street Station terminal.

The Underground Rail Loop, together with other improvements made by the Metropolitan Transit Authority has reversed the 30 year trend of decreasing patronage and has created a multi-station terminal system which copes with increasing peak commuter loadings, enhances the service and provides the means to improve the efficiency of operating the entire railway network.

CONCLUDING STATEMENT

The Melbourne Underground Rail Loop is a fine example of engineering excellence providing long-lasting benefits to the community.

To design and construct such a major engineering project within a busy Central Business District without significant disruption, complaint or litigation over a period of some fifteen years, is evidence of the high calibre of technical and management skills applied to solve the wide range of challenging problems which arose in almost every phase of construction.

The Connell Consortium and MetRail were granted a unique opportunity to demonstrate the contribution that the Engineering Profession can make to society. This contribution is acknowledged in practical terms by increased patronage on the metropolitan rail network and by the acceleration of building developments along the route of the loop adjacent to new stations, maintaining the vitality of the City of Melbourne and adding to the wealth of the State of Victoria.

It is relevant to quote an extract from US President Nixon's message to Congress in August 1969 when proposing a \$10 billion Federal aid program for improving public transportation.

"Moreover, until we make public transportation an attractive alternative to private car use, we will never be able to build highways fast enough to avoid congestion. As we survey the increasing congestion on our roads and strangulation of our central cities today, we can imagine what our plight will be when our urban population adds 100 million people by the year 2000.

"We cannot meet future needs by concentrating development on just one means of transportation. We must have a truly balanced system. Only when automobile transportation is complemented by adequate public transportation can we meet those needs."