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Front cover:
The Marly courtyard at the Richelieu Wing Louvre Museum, Paris.
(Photo: Peter Mackinven)

Back cover:
Kansai International Airport, with its mile-long terminal building, on the artificial island offshore from Senshu, Japan. (Photo: C.K. Hiwatashi)

Transport policy in the UK

Malcolm Simpson

1.

Background

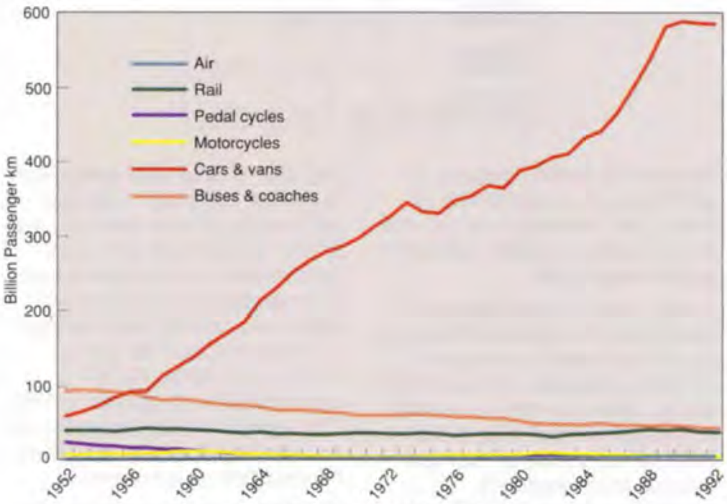
Transportation provision affects all aspects of life, not as an end in itself, but as a means of achieving most activities. It affects us socially, it influences our work locations, and has a direct or indirect bearing on all other activities in which we indulge.

It also has a direct impact on the work that many people in Arups undertake to provide the necessary infrastructure and its future operation.

The problems are evident. Roads are becoming more congested, not only in urban areas where peak periods are lengthening and speeds steadily decreasing, but also on inter-urban routes and in places with high leisure attraction, such as roads to holiday destinations, and in national parks like the Lake District. This congestion is bad for the nation's health and its economy. However, public transport use is reducing. Bus patronage is steadily declining and rail services are often less attractive in terms of cost and reliability than they were a few years ago.

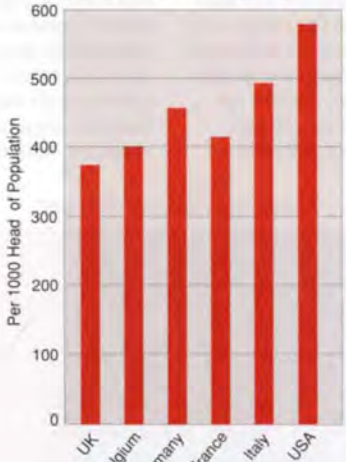
Solutions to these problems are not simple and the challenge facing transport planners and politicians covers a broad field of political, social, economic, and planning aspects. The complex inter-relationships between all these factors is not clearly understood and much research is being undertaken into them. The general desire for more movement set against the inevitably slow evolution of the built environment means that change is slow, even if current trends can be influenced.

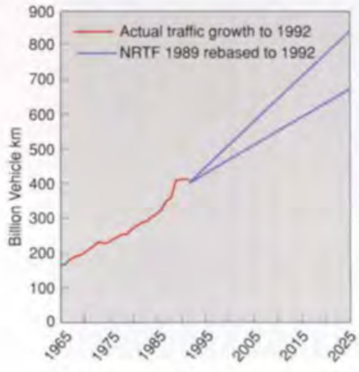
Whilst attitudes to transport are changing rapidly, the speed of this change cannot be matched by the necessary changes in social behaviour or the time needed to implement any major new transport infrastructure. Such development takes up to a generation from concept to implementation, so any solutions must look to the longer term and be set against the background of increasing environmental awareness and the desire for sustainability. Opposition to new transport infrastructure comes from all quarters, not only left wing activists, but also Councils in the Home Counties which have traditionally been the staunchest supporters of the current Government. The environmental effects of new transport infrastructure range from local impacts such as pollution, visual intrusion and loss of amenity space, to the global effects of increased CO_2 emissions.



2. Passenger transport by mode.

3. Cars and taxis stock 1991.





4. National road traffic forecast.

We are currently in a period of fundamental change in approach to transportation issues which will affect all of us socially, environmentally, and financially. There are very many misconceptions, and the wealth of transport data can be used to prove virtually any point that a particular interest group wishes to make. This article attempts to present some basic facts, the issues, and the possible ways forward in preserving accessibility and matching this with sustainability.

The process can be split into three simple aspects: the demand for travel; the supply of transport infrastructure; and thirdly the balance between these two and the options to achieve the balance.

Demand

The demand for travel is increasing. We are making more trips and longer trips. Fig. 2 shows the pattern of growth which is dominated by the dramatic and continuous increase in car use — not surprising in view of the car's unmatched flexibility for shopping, delivering children to school, and family holidays throughout Europe. Rail use has been steady, but road-based public transport has declined continuously over the years.

Apart from very minor reductions in growth rate at times of economic recession, the trend in car ownership has been and will continue to be steadily upwards. Fig. 3 shows the comparison of British car ownership with the major European countries and USA. It is evident that there is scope for further major increases in car ownership and use, as we are a long way from saturation level and below our European neighbours. Fig. 4 shows the Government's current prediction for road traffic growth and this demand will continue unless restrained by legislative or financial means.

Fig. 5 shows the increase in freight movement, again dominated by road use, with a steady decline in rail use. One current myth is that by increasing the latter our road traffic problems would be solved, but the reality is that even if we increase rail freight use by 50% — a major change against the trend — the difference in road traffic would amount to only a few months growth, a totally insignificant amount in overall volume although there could well be justification in terms of environmental benefits.

Supply

Growth in supply of transport infrastructure does not match demand growth. Fig. 6 shows the recent increase in road length in Britain: the density of vehicles in this country is over twice that in France and the USA, and 40% higher than in Germany. Provision of road space does not, therefore, match our neighbours and the increase is but a small proportion of the increase in demand. Growing pressures are put on urban main roads: the laudable provision of traffic calming schemes to prevent rat-running through sensitive areas tends to put more traffic on already congested major roads.

The length of rail lines in the UK has halved since the War. No new main line has been built this century, although there has been some new rail construction in urban areas, mainly London. Tramways reached their peak in the 1920s and then virtually disappeared. Recently, new light rail systems have been opened in Manchester and Sheffield which, whilst providing a good local service, have had little overall impact.

Demand versus supply

Balance between supply and demand is at the centre of the current debate. Demand growth far outstrips the possible increase in supply of road-based transport infrastructure, which clearly cannot be increased significantly in terms of new provision. Even the Department of Transport accepts that there is no way that environmentally acceptable schemes can match demand.

As supply cannot meet demand, the demand must be limited to the supply in order to avoid costly congestion. How can an optimum balance be achieved between the demand for and provision of travel, with acceptable consequent environmental conditions? Achieving this balance is made more difficult by the totally different appraisal and pricing techniques used for road and rail. The former is done on an economic basis with the benefits being primarily user time savings and accident savings. Rail, on the other hand, is assessed on a financial basis in terms of cash received from fares and the need to provide a return on investment. Even the thinking is biased. Road expenditure is often described as an investment, whilst rail funding is called a subsidy.

It is essential that a coherent appraisal method be developed for UK transport systems in order to achieve balanced solutions. Road use is paid for largely by annual payments, but public transport is paid for fully at time of use. This leads to an incentive to use cars but a constant deterrent to public transport use.

5. Freight transport by mode.

6. Increase in British road length.

	1981	1991	% increase 81–91
All roads (1000km)	342	360	5.3
Motorways (1000km)	2.7	3.1	14.8
Road traffic (billion vehicle km)	277	412	48.7

In order to obtain a real choice of travel mode, the balance of spending should be reviewed as choice is currently getting less. The road lobby claims, rightly, that the income from road-based transport is up to four times the expenditure on road construction and maintenance. The counter argument is that if full costs including environmental effects are taken into account, the balance is in fact reversed. Rail fares are increasing. Commuting fares into London are the highest in Europe and are three to four times the equivalent fares in other major European cities. Britain's rail system receives less Government subsidy than any other in Europe.

The effect of British Rail privatization is at present unknown. If any guidance can be obtained from bus privatization, the trend is that more services operate and costs are reduced — largely because bus fleets are ageing and have not been renewed — but the net result has been a decline of approximately 25% in patronage since privatization in 1986. The current imbalance between road and rail is therefore likely to increase if current policies are pursued.

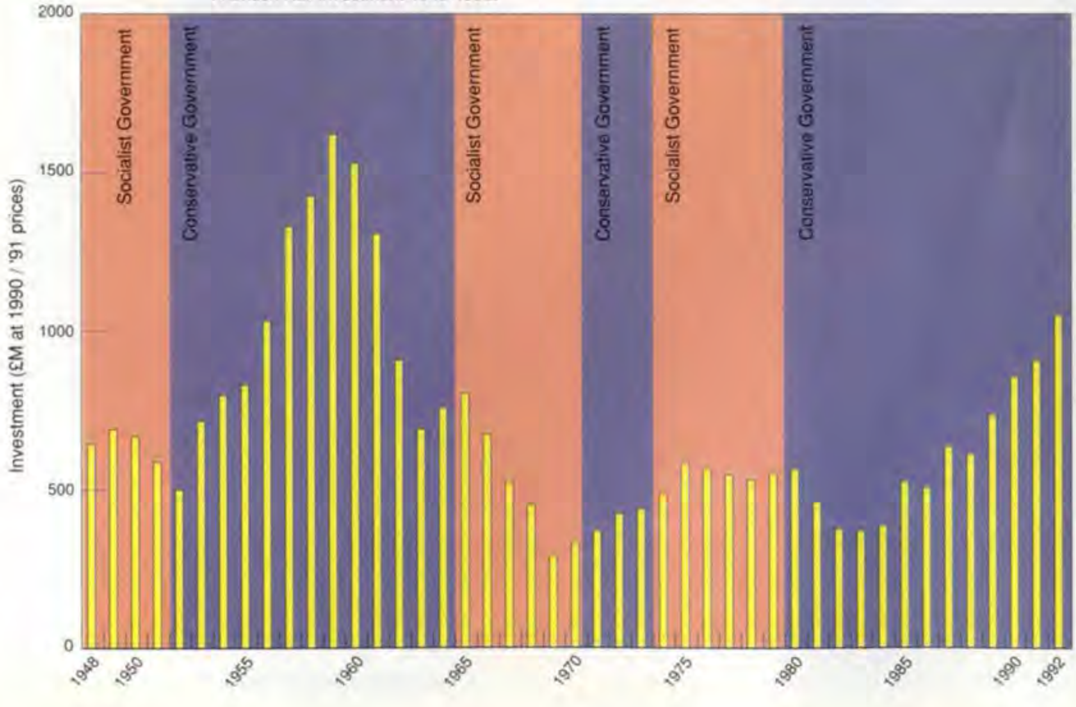
The desire to reduce car travel is at the forefront of the planning debate. Guidance from the Department of the Environment is focusing development on town centres where it is claiming that public transport will reduce car use. Out-of-town shopping and business park developments have become very popular in recent years. These are extremely attractive to car users, and travel to alternative locations would be more expensive and less convenient for the vast majority of the population. In addition, recent research on office locations has shown that, even if good public transport exists, the desire will remain to use a car for access. Possible changes in overall travel demand cannot be immediate as land-use changes are very slow and travel patterns well-established. Social use of cars has increased significantly, with leisure trips the fastest-growing component. Would we accept restrictions on use of our car for holiday and social purposes? It would be difficult enough to stop the current trend, let alone reverse it, but many people believe that this is essential if we are to achieve sustainability.

Options

We must make better use of our entire existing infrastructure. Road space should be effectively managed: London's Red Routes, for which Arups carried out the pilot study, are an example of urban road optimization where parking is limited, through traffic including buses has priority, and effective management systems operate. Another approach is prioritization of certain types of road users: commercial and public transport vehicles would have priority through measures such as segregated lanes or pricing mechanisms. An example is our work on bus priorities in Edinburgh (see facing page).

It is essential that a major effort is made to change modal split, which can only be done by making public transport relatively more attractive in convenience and cost terms. It is inevitable that car use will be limited by increasing fuel cost and taxes and tolling in appropriate areas. Urban parking controls will be increasingly introduced, by limiting provision or by higher charges. It is mainly by increasing the cost of car use that growth will be contained. It will also be necessary to invest in public transport to provide a real alternative.

7. British Rail investment 1948-1992.



One idea is that increased road charges can be used to improve public transport. Transport planning should cover all modes, not just roads. The work Arups are doing on multi-modal planning in West Glamorgan and Southampton, and public transport alternatives to motorway construction, are forerunners of this approach.

Walking and cycling should be encouraged by provision of segregated, environmentally acceptable routes, but these will have a limited impact on car use, particularly in view of the growing safety and social problems associated with these modes.

The way that an acceptable balance between transport modes can be achieved is at the forefront of political debate. It is interesting that there is little difference between the main political parties and that they both wish to involve a maximum amount of private sector investment, but this can only be made against a logical background of risk definition. It is not reasonable for the private sector to bear the planning and political risk of new transport infrastructure, but quite reasonable for them to bear the construction and operating cost risks. The current Government has not clearly defined these rules and this is hampering private sector involvement in the transport field. Rail investment has been intermittent. Fig.7 shows the historical trend in real terms. It can be seen that there is no clear pattern related to the political party in power and we are still below the investment levels of the 1960s. The apparent optimism of the recent increases in funding has been dampened by the Government's latest proposals to reduce investment in the next few years.

Governments have never displayed a long-term commitment to public transport. None has prepared national forecasts for public transport use although all have published road traffic forecasts.

What are the conclusions? We will inevitably see less building of major new infrastructure to provide for demand. There should be positive demand management. There will be increasing emphasis on public transport. Ways to manage the existing network efficiently will be developed including on- and off-vehicle road information systems. There is a need for better integration of public transport services to improve flexibility, although privatization could well hamper this aim. There will be increasing emphasis on control systems to manage movements of vehicles and limit and control parking. We are going to pay more for our travel, but the main conclusion is that we should demand an overall transport strategy for the country which achieves an appropriate balance between all modes and will help us to achieve the sustainable goals that have been set.

Illustrations:
1: M40 Motorway alongside Paddington-Birmingham railway (photo Keith Law).
2-7: Peter Speleers.

Malcolm Simpson is a Director of Ove Arup & Partners Transportation and Environmental Groups.

Edinburgh Western Corridor Busway Study

Gavin Dunnett Gordon Henderson

Background

In common with many UK cities, travel patterns in Edinburgh are gradually changing in response to population and land-use pressures. With around 425 000 population it is not large, but it remains a vibrant commercial, legal, and financial centre, as well as an internationally renowned cultural focus. Having successfully resisted some of the more excessive road-building plans of the '60s and '70s, when the city enhanced its reputation for cultural conservatism, the challenge for today's transport planners is to find solutions to the ever-increasing problems of congestion which respect the integrity of the unique commercial and cultural life of Scotland's capital. Edinburgh's population has been slowly declining over the past decade with a corresponding rise in surrounding areas (although significant numbers still live in the city centre). Similar decentralizing pressures have been experienced through businesses and shopping moving to the fringes. Although notable successes have been achieved in revitalizing Edinburgh's local and suburban rail services, these only account for some 4% of the morning peak of journeys to the city centre. The use of buses has declined by 12% since deregulation in 1985, although bus remains an important part of city centre travel. In contrast, car ownership in Lothian grew from 220 to 317 cars per 1000 head of population between 1981 and 1990, the fourth highest rate in the UK. In the same period, traffic flows in the study corridor increased by 40%.

1. Edinburgh.

2. Guided busway in Essen.

In past years, Lothian Regional Council (LRC) have tried to enhance public transport's attractiveness, both for those with and without cars. In 1989 they decided on a metro system — street-running trams on two main alignments, north-south and east-west — but it was later recognized that funds were likely to preclude its implementation for many years.

City of Edinburgh District Council (CEDC) subsequently commissioned a preliminary study into the potential for a low-cost busway using existing roads: an interim solution on a much shorter timescale than a metro, but offering significant improvements over existing bus services. LRC in turn resolved to commission a more detailed operational, financial, and engineering feasibility study into a busway in the city's western corridor. In September 1992 Arups were appointed to carry this out by a client consortium comprising both Councils plus Lothian and Edinburgh Enterprise Ltd. and the British Airports Authority. The objectives were to provide:

- a connection to Edinburgh Airport
- links to and from the South Gyle development area
- an express connection between the city centre and the western suburbs
- 'Park & Ride'.

The study was to include an assessment of the potential role of the private sector in financing and operating a system.

Bus-based Light Rapid Transit

The concept of Light Rapid Transit (LRT) is generally associated in the UK with the reintroduction of street-running trams, as in Manchester and Sheffield. Buses have a poor image and are seen as a last resort, subject to the same delays as other traffic, even when priority measures are introduced. There are, however, many examples around the world of buses as a form of LRT; indeed a successful segregated busway network has been operating in Runcorn New Town for over 20 years. The use of segregated rights of way for conventional buses is the key component of systems in France (parts of the Paris orbital tramway), Belgium (Liége), Netherlands (Arnhem), Germany (Essen and Mannheim), Turkey (Istanbul and Ankara), Brazil (Sao Paulo), and Australia (Adelaide)

Those in Adelaide and Essen use a kerb-guidance system, giving some of the advantages of rail-based LRT.

3. Guidance system.

The bus is steered via a small guide wheel attached directly to its steering axle, which bears on a concrete upstand similar to a conventional kerb. In the guideway the vehicle requires no directional intervention from the driver, so the required right-of-way is reduced and level boarding at stops is possible. Also, noise levels can be reduced if grass is planted between the guides; reflection from the road surface is a significant contributor to conventional bus noise. Away from the guideway, the vehicle can operate as a standard bus; this flexibility distinguishes guided bus from conventional rail. A short section of guideway will be introduced in Leeds as part of a package of bus priority measures in 1995.

System specification

Public transport systems are defined by elements specific to their own objectives and locations, so the Edinburgh Western Corridor Busway would always be unique to its own environment. However, it is also potentially the only system of its kind in the UK, and in order to evaluate its viability, a specification was evolved which both met local objectives and was consistent within itself:

Right-of-way

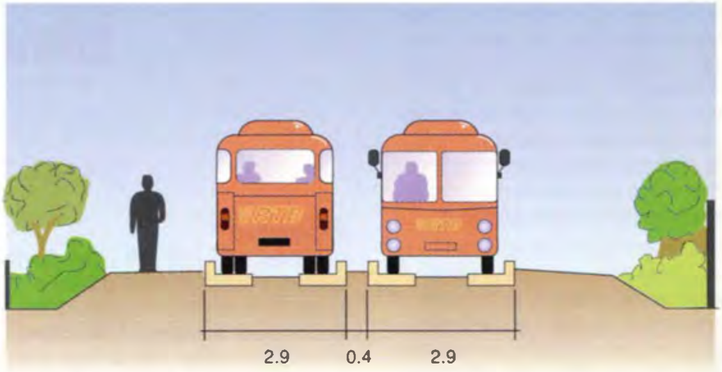
The basic route runs from a Park & Ride site near the Airport, through South Gyle, and along the existing Glasgow railway corridor into the city centre, where it uses existing roads before terminating close to St. Andrew Square at the centre's east end. The route can be largely segregated from existing roads and traffic — an important factor when competing with on-street services running on existing radial routes. For the same reason, it was decided to design the alignment to the highest practical speed (85kph) that avoided unreasonable cost or environmental penalties.

The choice of system was not obvious at the outset. However, on several sections of the route the alignment passed close to existing property where land-take would be an issue, so three different cross-sections were examined and costed: conventional 7.3m single carriageway, reduced 6.75m carriageway, and 6.2m guideway. The latter was based on a proprietary German precast concrete system and was more expensive, but the increased costs were offset by savings on structures, earthworks, and land.

To maintain maximum segregation it was decided to restrict access to trunk sections of the route to one intermediate point, where local services serving the western suburbs of Edinburgh could join the trunk busway via grade-separated sliproads.

Operating characteristics

One of the advantages of a bus-based system is the ability to differentiate services for particular market segments by running a mixture on the same infrastructure without the interchange penalty common with rail-based systems. Thus, express trunk services can co-exist with local stopping services feeding into the system



4. Cross-section of guideway.

from surrounding areas. Differentiation by price is also possible. To evaluate and comply with the study brief, three sets of services were postulated, although in practice many variants are possible:

- Park & Ride: express five-minute service (10 minutes off-peak). Every second bus would also serve the Airport.
- Wester Hailes suburban service: limited-stop, five-minute service (10 minute off-peak); on-street feeder service joining the trunk section of the Busway midway.
- South Gyle circular service: limited-stop, 10-minute service (in each direction); on-street feeder service serving existing and future development.

Both existing regional bus services and seasonal tours and excursions would also be likely to use the busway. In addition, Murrayfield Stadium is on the proposed line — another potential source of additional revenue.

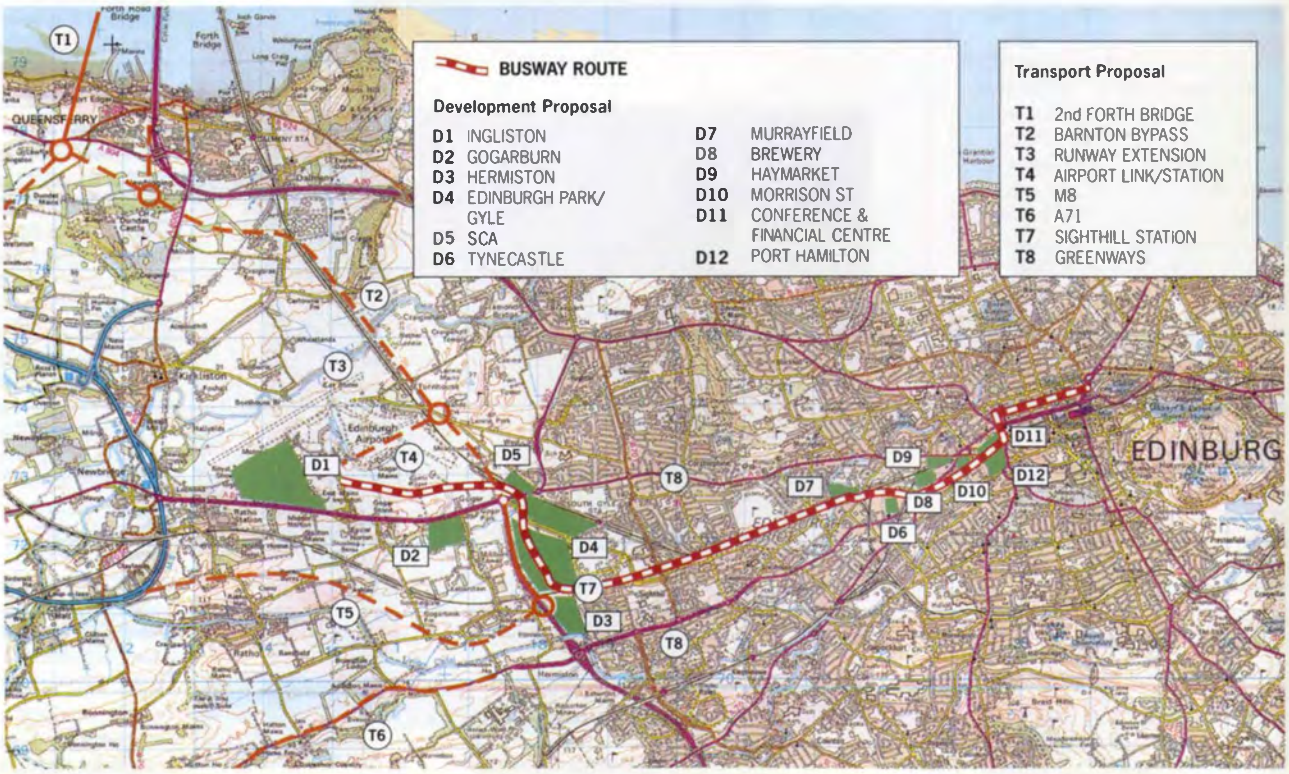
Vehicle characteristics

The buses themselves are an important factor and in this, as in other aspects of the system definition, the notional 'ownership' is fundamental.

Clearly, with a public or semi-public system the promoter and/or operator of the busway will have little control over the type of vehicles using the system.

For a private system, where it is possible to specify vehicles, choice will be governed by two things: image and function. A distinctive image is important for a private service and the novelty value associated with guided operation or articulated 'bendy' buses would be a consideration in vehicle choice. It would also be desirable to replace the fleet at reasonable intervals; five years was assumed for the purposes of evaluation.

The strictly functional requirements of the assumed service patterns would require a maximum unit capacity of 50, so a standard luxury coach could suffice without crush loading. On local services, where some peak period crush loading might be more acceptable, smaller vehicles could reduce capital and operating costs.



5. Transport and development proposals.

Alternative sources of motive power were considered unlikely because of the additional costs of vehicles and of overhead wires and supports for use by electric trolleybuses or duo-buses.

Forecasting

The basic demand forecasts for the busway came from LRC's strategic transport planning models. However an important objective of the system is to attract existing car drivers to transfer to Park & Ride — not covered adequately by these models — so the data was processed on Arups' EMME/2 transport planning program. Some 4000 questionnaires were also distributed to drivers on the A8 and A71 radial routes, to gain information on journey origins, purpose, and degree of 'captivity' to car. In addition, detailed market research was undertaken to measure drivers' responses to the new travel opportunity. 25 000-30 000 passengers per day are predicted to use the system.

The busway's basic attraction is its relatively high benefit-to-cost ratio compared with a rail-based solution, attracting a high proportion of available benefits at an order of magnitude lower cost. Social cost-benefit analysis, where time and accident savings are given a notional monetary value, shows that the project has a substantial return in conventional public sector project terms. A £30M surplus of benefits over costs (net present value) is predicted for the project.

Project implementation

Legislative context

The roads authority could obtain powers to construct the busway using existing legislation. Following inclusion of the project in the Regional Structure Plan review, the route would be promoted as a Special Road by application to the Secretary of State for definition of an appropriate Use Class. The option would then remain open for the promotion of a Toll Order under the New Roads and Streetworks Act 1991. The timescale to promote such a scheme would be no different from that for any major road proposal. Any scheme promoted under existing legislation would in theory be open to any bus operator.

An alternative would be to seek parliamentary powers by the promotion of a Provisional Order under the Private Legislation Procedure (Scotland) Act 1936. This is effectively a shortened private bill procedure and can in some instances become a conventional private bill. A local authority could not promote a Provisional Order for a conventional busway since other powers are available. However, they might be able to promote a guided busway in this manner. A private company could use the procedure in either case.

The fundamental problem in obtaining Parliamentary powers containing any form of exclusivity to a particular bus operator is the provisions of the Transport Act 1985, which makes it illegal to inhibit competition in any way between operators seeking to promote services.

Funding

Four financing options were considered, ranging from full public sector ownership to the maximum level of private sector ownership:

Option 1:
Public sector ownership and operation
Based on predicted operating costs and revenues, it is likely that a typical public sector loan for the full out-turn cost could be repaid with interest at 6% p.a. (real). In testing an option based on local authority borrowing, it was assumed that the required powers would be available. The financing regime tested was based on a 25-year 50% European Investment Bank loan and a 20-year 50% local authority bank loan.

Option 2:
Public sector corporate ownership under a 25-year concession
In this option a Build Own Transfer Local Authority Concessionaire Company (BOTLACO) would be formed with a nominal shareholding owned by, and with management supplied by, the local authorities, who would grant BOTLACO a 25-year concession. Construction, land purchase, and arrangement costs would be paid for by a 25-year leasing arrangement. Similarly the vehicle fleet would be purchased using a five-year leasing arrangement with renewal at each change of fleet date. These leases would be taken out by BOTLACO, backed by a guarantee from the local authority owners to cover any shortfall in monies available to meet the lease payments. BOTLACO would appoint an operator under a contract for a monthly usage charge, plus an annual percentage of net profit over a given amount. This option involves total transparency of public sector ownership — perhaps a problem under Treasury rules — although the publicly-owned but privately-operated enterprise companies in Scotland may provide the necessary precedent.

Option 3:
Private sector corporate ownership for a 25-year concession
In this, a Build Own Transfer Concessionaire Company (BOTCO) would be formed with a nominal private sector shareholding. The local authorities would grant BOTCO a 25-year concession, who would enter a joint venture arrangement with an operator. This would stipulate a minimum operator fee of, say, 1% net revenue, but thereafter lease payments would have first call on net revenue. BOTCO would pay 50% of the net revenues it received to the local authorities as a fee for lease short term guarantee. If this were called in, BOTCO would pay up to 100% of the net revenue it received to the local authorities until the shortfall payment made by them had been repaid.

Option 4:
Private sector corporate ownership in perpetuity
Here a Build Own Operating Company (BOOC) would be formed with private sector shareholders and equity funds sufficient to meet land costs and working capital needs — say £3M. Construction and arrangement costs (less the £3M equity payment) would be paid for using a 25-year leasing arrangement. Similarly the vehicle fleet would be purchased using a five-year lease with renewal at each change of fleet date. The land would be purchased by BOOC. Because there would be no supporting local authority guarantee to cover any shortfall in the payments, BOOC would have to be given grant monies — c.£6M — to cover the security needed to reduce or support the lease payments, or both. The higher the grant element the lower, up to a point, would be the annual lease cost.

Comparison

One way of comparing the four options is to present a net present value of the financial surplus indicated in the funding case for each option. These are remarkably similar, with Option 4 (pure private sector) marginally best at £7.44M and Option 1 (pure public sector) a close second with £7.22M. Options 2 and 3 produced values of £6.96M and £6.89M respectively.

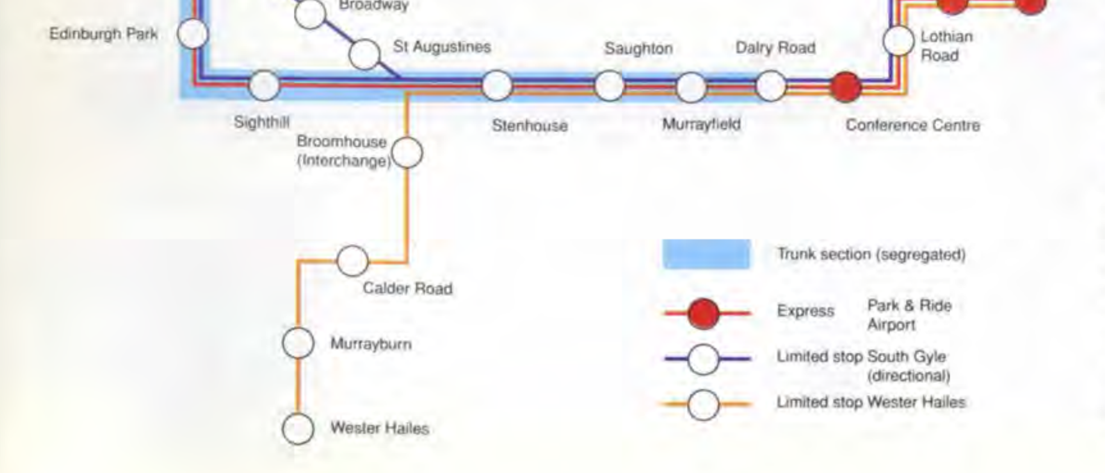
Conclusion

The study findings indicate that, as a transport infrastructure investment, the Edinburgh Western Corridor Busway shows great potential both as a joint public/private sector project and as a conventional public sector project. Its eventual form as a transport system will depend on which of these two broad paths is followed in its promotion. The success of the Busway will, however, depend on its promotion as an LRT system, distinct from on-street services in terms of journey time and image.

The project has engendered considerable interest in the two local authorities despite impending reorganization. Further work is currently being carried out to identify a preferred alignment for formal adoption by LRC and CEDC. Also, because of the project's relationship to the 'Setting Forth' proposals and its potential to attract private finance, the Scottish Office have jointly with LRC commissioned Arups to investigate the potential to extend the Busway across the Forth estuary as part of the overall Setting Forth package.

There is little doubt that if we are to avoid the creeping paralysis of congestion and pollution in our cities, our attitude to and investment in public transport must move more in line with our European competitors. The Edinburgh Western Corridor Busway would be unique in the UK. At a time when central funds are limited, we must also seek imaginative funding and solutions to achieve these overall aims and ensure that the quality of life provided by cities such as Edinburgh can be retained in the future.

6. Service patterns.



Credits

Client:
Lothian Regional Council
City of Edinburgh District Council
Lothian and Edinburgh Enterprise Ltd.
British Airports Authority
Lead consultant:
Arup Transportation Gordon Henderson, Gavin Dunnett, Paul Roberts, David Anderson, Andrew Marsay, Joe McLaughlin, Alasdair MacLeod, Stephen Harrison, Iain Bell, Duncan Birrell, Ian Stenhouse, Euan Atkinson
Specialist consultants:
Accent Marketing & Research
Finance for Enterprise
Alan Howes Associates
Illustrations:
1, 2: Gavin Dunnett. 3-6: Jon Carver.

Hong Kong Kai Tak Airport: Taxiway Bridge 3

1.

Introduction

A bridge on which aircraft can taxi sounds interesting. As part of improvement works to Hong Kong's Kai Tak Airport, one has been built across the Kai Tak nullah to link the existing taxiway with the new parking apron in Kowloon Bay.

In January 1992 the Airport Division of the Hong Kong Civil Engineering Department invited tenders from contractors to design and construct the bridge, including its lighting, utilities, and associated pavement works (which included repaving a section of taxiway along the Kai Tak runway), in a 15-month contract period. Dragages et Travaux Publics were awarded the job for HK$109M (£9M) in May 1992. They co-ordinated the design; their sister company, VSL Hong Kong Ltd., designed and supplied the precast deck structure; and Ove Arup & Partners were appointed for all the remaining works including the alignment, drainage, aircraft load geometries, substructure and foundations for the bridge, utilities and lighting, and the airfield pavements. Taxiway Bridge 3 was the first major bridge in Hong Kong tendered on a design and build basis. Part of it is located within the Airport Restricted Area and certain work, including some foundations, could only be carried out at night, after the airport closed.

Span arrangement and deck structure

With a total length of 225m over seven spans, it is one of the longest such bridges in the world, its 44m taxiway about as wide as 12 highway traffic lanes. The deck, supported by 22 precast prestressed concrete T-beams per typical span, is only 1.6m deep overall, including a 220mm thick in situ concrete topping, but has to carry the current heaviest passenger aircraft, the 400 tonne Boeing 747-400F. The need for a 20m navigation channel for emergency and maintenance vessels, and to match existing levels at both ends of the bridge, meant reducing the structural depth to 1.125m depth for the navigation span, but apart from this, there were no particular contractual constraints on span lengths and pier positions. Ground conditions implied relatively long piles, favouring longer spans, but lack of land access made it preferable to maximize precasting within the limits of maximum weight and length of precast members. The optimum span length was found to be about 36m, and an arrangement of 29.6+36+36+21.5+36+36+29.6m was finally adopted.

The T-beam was chosen over a variety of shapes as it provided the most economical structural section, the flange acting as formwork for the in situ topping. The T-beams were designed to span simply supported under self-weight and topping slab loading, and as a continuous structure under aircraft live loadings. The continuous deck structure eased the problem of lack of structural depth at the navigation span, and made it possible for lateral loads (seismic, ship impact, aircraft braking) to be shared by all the piers.

Alignment and deck profile

The vertical alignment had to tie in with existing levels (about 5m Principal Datum) and gradients at both ends of the bridge, while the navigation channel, up to 4.86mPD under the bridge, had to be maintained. The alignment design follows International Civil Aviation Organisation (ICAO) rules, which require a taxiway slope not exceeding 1.5%, a minimum vertical transition radius of 3000m, and an unobstructed 300m view of the taxiway from any point 3m above it. The final alignment adopted suits all requirements, and a transition strip 112m long in the existing taxiway ties in the levels and gradients at the end of the bridge.

Deck loadings

The major special loading was the full taxiing weight and braking load of a 400 tonne Boeing 747-400F. Boeing provided information on wheel positions and loadings, but the orientations of the aircraft to give critical load combinations were predicted by the swept path of the landing gear generated by the TRACK program. The envelope of the swept paths, plus a margin of 4.5m, forms the central region where both serviceability and ultimate limit states were considered. Other special loadings include emergency and maintenance vehicles at 10kN/m^2, and impact on the bridge structure from a vessel of 350 tonnes displacement travelling at 4 knots.

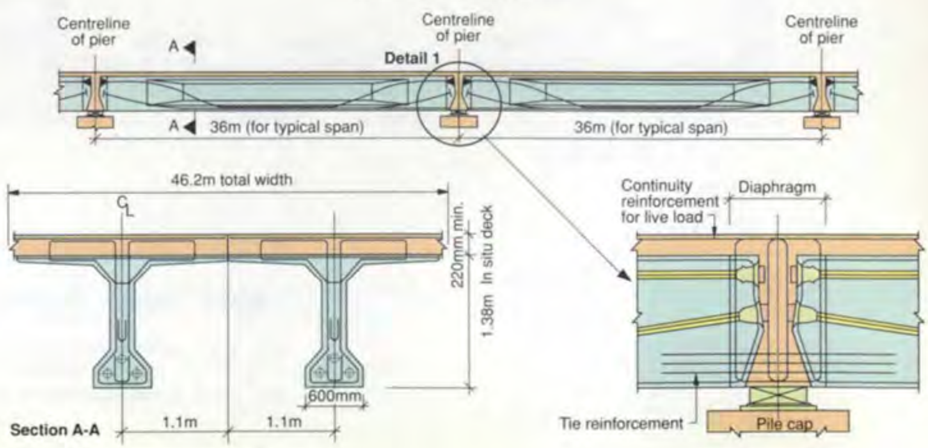
Deck drainage

The deck drainage system was designed to cater for 1 in 200-year storms. A W-shaped deck crossfall was chosen above the navigation channel to save about 110mm structural depth compared with a conventional inverted V-shape crossfall. The W-crossfall gradually transforms, with the maximum slope of 1.5%, into the inverted V-shape at both ends of the bridge to tie in with the drainage profile. All gully gratings in the taxiway can withstand aircraft wheel load, and are suitable for use in airports.

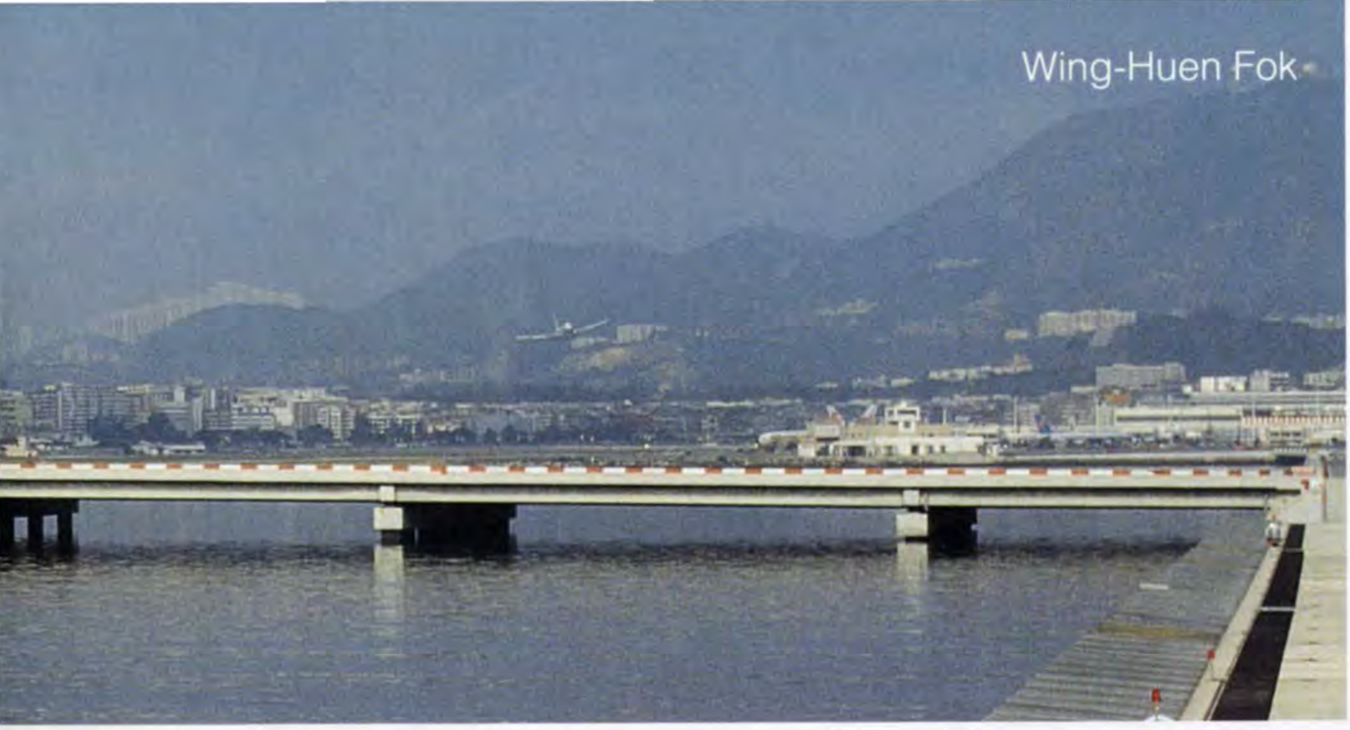
Bearings and movement joints

Purpose-made 600mm square elastomeric bearings between 250mm and 300mm thick were used under the intermediate supports, and sliding elastomeric laminated bearings with PTFE and stainless steel surfaces catered for the high movements at end supports. At the free ends of the deck structure, movements of up to 190mm due to shrinkage, creep, and thermal effects were predicted. To cope with these, and the 747-400F's extremely high wheel loads (up to 31 350kg), 40mm thick finger plates weighing in excess of 500kg/m bridge the gaps between the ends of the superstructure and abutments.

2. Section through deck.



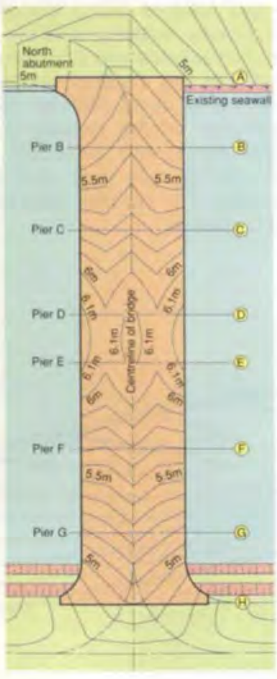
Wing-Huen Fok



Marine piers and abutments

The piers are reinforced concrete crossheads on driven tubular steel piles with concrete infill. A relatively large diameter of 1.2m was chosen to avoid raking the piles, lateral forces being taken by their bending resistance.

The reinforced concrete abutments are supported on minipiles and H-piles. Piling on the runway side was only possible after closure of the airport at midnight, and by 6am the runway had to be ready for use again. All construction, including mobilization and demobilization of all plant and equipment, and cleaning and inspection of the runway prior to operation, had to be packed into six night hours. Percussive and bored piling were both unsuitable for various reasons, but minipiles were ideal, needing only small, easily movable drilling rigs. For the abutment on the parking apron side there were no particular constraints except the proximity of the seawall and its rubble mound foundation. Vertical and raked steel H-piles were adopted.



3. Bridge plan.

Both the crossheads and abutments were shaped to fall in the same profile as the deck surface, thus allowing a more uniform thickness for the deck structure.

Pavement

The airfield pavements are classified into stressed and non-stressed types and are either rigid or flexible. The non-stressed pavement is located beyond the edge of taxiway where the chance of supporting aircraft load is low. Pavements were all designed to US Federal Aviation Administration standards. The structural concrete topping of the deck forms the running surface for the bridge taxiway. On both ends of the bridge, the pavement is mainly rigid: 350mm thick rectangular concrete pavement panels on top of a 150mm thick concrete subbase above soil, the latter either compacted so that a 100 tonne proof roller could pass over without any noticeable depression, or prepared as a thick layer of graded rock and granular materials.

Along the existing taxiway, a strip of flexible pavement was repaved and extended to suit the new geometry and levels.

Utilities, lightings, signs and markings

These followed ICAO rules and are consistent with the present systems at Kai Tak Airport. Covers of drawpits and lightings in the taxiway are all capable of withstanding aircraft wheel loads. Installations above ground, such as signs and fire hydrants, are away from the taxiway, and are sufficiently low to prevent damage to the outboard engines of aircrafts.

4. Aircraft taxiing onto bridge.

Construction

As 'design and build' has the advantage of a shorter implementation programme it is interesting to look at the actual progress achieved:

Start of construction: 18 May 1992

Design of main structure: 3 months

First pile driven: July 1992

Total duration of piling: 4.5 months

Installation of 44 minipiles: 3.5 months

Precasting of 154 beams with seven moulds: 5 months

First beam placed: December 1992

First pour of in situ deck concrete: February 1992

Duration of in situ concreting: 3.5 months

E&M works and other installations: 3 months.

Handover to client: 15 August 1993.

Conclusion

It is remarkable for a new bridge of this kind serving an airport to be replaced by another in a few years' time. Kai Tak Airport will be superseded by Chek Lap Kok by 1997, when China resumes sovereignty of the Territory. Meanwhile, this bridge is a very successful application of 'design and build': despite the short construction time and severe restrictions of working at an operating airport, it opened on time and within budget — a fine example of co-operation between client, authorities, consultant, contractor, and designers.

Reference

(1) FUNG, H.K.C., FOK, W.H., and YOUNG, B. Design of the Kai Tak Taxiway Bridge No. 3. Hong Kong Engineer, pp.39-44, October 1993.

Credits

Client:
Hong Kong Civil Engineering Department
Contractor:
Dragages et Travaux Publics
Contractor's designer:
Ove Arup & Partners Mike Kaye, Roger Alley, Alan Kam, Fergal Whyte, Brian Littlechild, Wing-Huen Fok, Kei Fung, Michael Ho, Kelvin Tang, Westwood Hong
Deck design & build sub-contractor:
VSL Hong Kong Ltd.
Illustrations: 2, 3: Ove Arup & Partners
Photos: 1: Colin Wade. 4: W-H. Fok

Wing-Huen Fok is a civil engineer and Associate of Ove Arup & Partners Hong Kong Ltd.

Richelieu Wing, Louvre Museum, Paris

Alistair Lenczner Andrew McDowell Andrew Sedgwick

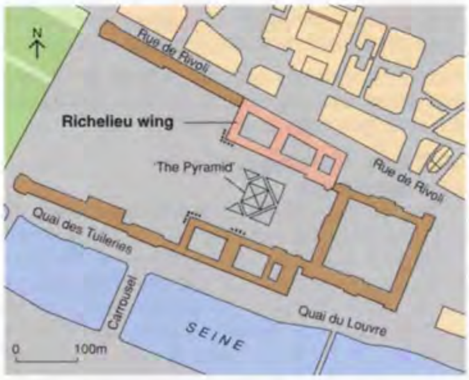
Introduction

In November 1983 President Mitterrand set in motion a major redevelopment of the Louvre Museum and the adjacent Tuileries Gardens. 10 years later, almost to the day, he returned to open the newly-restored Richelieu Wing, adding 22 000m^2 and 178 rooms to one of the largest museums in the world.

Until this time the Museum was contained within the south and east wings of the Palais du Louvre, now named the Denon and Sully Wings. Since 1989 public access has been through I. M. Pei's glass pyramid in the centre of the Cour Napoleon. The Richelieu Wing (L'aile Richelieu), to the north between the Cour Napoleon and the Rue de Rivoli, was built in the mid-19th century as government offices. In the late 1980s the Ministry of Finance vacated it for new offices in Bercy, and redevelopment began.

The eight cramped office floors have been removed and replaced with three floors of new museum space. Sculpture and Oriental Antiquities are at ground floor, which includes three internal courtyards transformed from car parks for civil servants into covered sculpture courts. The design of the new glazed roof structure over these was inspired by Peter Rice, who worked closely with I. M. Pei to create dramatic spaces. Two teams from Ove Arup & Partners, both under Peter Rice's leadership, were commissioned by the Etablissement Public du Grand Louvre (EPGL) to design these roofs and to develop a scheme for the natural lighting of the Paintings Department.

The Decorative Arts Department is on the first floor of the new wing, with the Paintings Department at the top of the building on the second floor. Here, over 40 new painting galleries are dedicated to the works of the Northern Schools, such as Van Eyck, Rembrandt and Vermeer. A further 19 rooms show the early, 14th-17th century, part of the French paintings collection. A further set of basement galleries display for the first time the Museum's extensive collection of Islamic art, and connect the new wing to the public entrance hall beneath the pyramid.



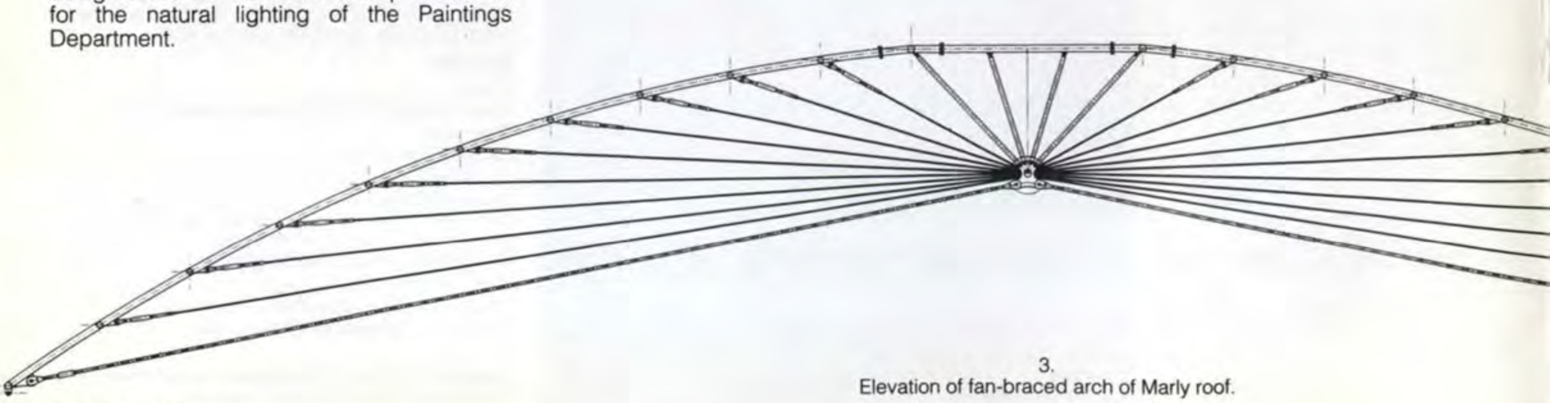
2.
Site location.

Courtyard glass roofs

Structural scheme

The design of the glazed roofs to cover the three interior courtyards (now called Marly, Puget and Khorsabad) of the Richelieu Wing was a critical part of the architect's overall plan for the Louvre remodelling.

The three courtyards all have irregular tapering plan geometries, with the internal north-south width reducing from over 41m at the western end of Marly to under 28m at the eastern side of Khorsabad. In designing the structures to cover them, careful studies of different structural plan setting-out options were made to find one which best resolved the irregularities without drawing undue attention to them, and which allowed the number of different glazing sizes to be rationalized. The general shape of each new roof is that of a shallow vault with hipped ends of similar curvature, the roof heights being limited to preserve the Louvre's existing roofline silhouette. The roof structures are propped off the cornices topping the existing courtyard façades by a series of short vertical posts. This allows openable smoke outlets to be incorporated into the space provided beneath the eaves of the new roof, and also gives the impression that the new structures hover over the courtyards.



3.
Elevation of fan-braced arch of Marly roof.

◀1.
Long section through the Richelieu Wing, showing from left to right the Khorsabad, Puget and Marly courtyards.

4.▶
Interior view of roof over Cour Puget. In the foreground is a marble statue (c.1830) of Spartacus by Denis Foyatier (1793-1863).

The two larger courtyards, Marly and Puget, have similar types of roof structure to each other, incorporating fan-braced tubular steel arches spanning across their width. The smaller Khorsabad has a simpler tied-arch structure, though with a similar external shape. The dimensions of the structural elements were an important consideration in the roof design, not only to reduce visual 'weight' but also to avoid casting deep shadows at floor level within the sculpture courts. Each of Marly and Puget's main arch members has a tubular section Ø 139.7mm, whilst the purlins spanning between them have a Ø 114.3mm tubular section. The hip members forming the corners of each roof are a thicker Ø 168.3mm.

The butterfly-fan bracing in the arches of Marly and Puget was devised to reduce the buckling length of the main arch members, thus allowing their section size to be minimized. The cables forming this fan bracing pass through a special node clamp detail beneath the arch crown. The roof structure supports gravity loads by a combined action of systems. A three-dimensional spine truss running under the top ridge of the roof is supported by the fan-braced arches which traverse it across the width of the courtyards. Additional support is provided by the action of the fan-braced arches linking to the ends of the spine truss. Alternating with the fan-braced arches on each side of the ridge are chord-tied arches spanning between the spine truss and the outside edge of the roof.

The curved grid surfaces formed by the intersecting tubular arches and purlins are given in-plane shear stiffness by series of diagonal criss-crossing ties which intersect with the tubular junctions. These tie members allow gravity forces to be redistributed between arches and help support the corners of the roof by shell-type action. The diagonal tie bracing is also important in providing overall sway stability for the roof under horizontal wind loads or asymmetric snow loads. The roof structures are stabilized horizontally parallel to each side of the respective courtyards by vertical bracing between the props midway along each side. This arrangement allows the whole structure to expand or contract symmetrically under thermal loads. In the unlikely event of a net vertical uplift loadcase under very extreme wind conditions, vertical loads are transmitted through the structure by the combined action of the grid shell with the hip members and spine-truss, forming a shallow quadrapod working in tension.

Structural justification

The non-linear structural behaviour of the arches restrained by the fan cables required a special analytical method to demonstrate its performance under load. Computer software specially developed by Arups to analyze non-linear behaviour took into account the possibility of certain ties going slack as the structure was loaded. The same software was also used to demonstrate the overall buckling behaviour of the arch, which would otherwise have proved difficult to justify.

Separate computer models were analyzed firstly to study the two-dimensional behaviour of the fan-braced arch and later the overall three-dimensional performance of the complete roof. Wind pressures on the roof were based on wind tunnel tests carried out by the CSTB at Nantes, and snow loadings allowed for the possibility of deep drifting at the edges against adjacent roofs.

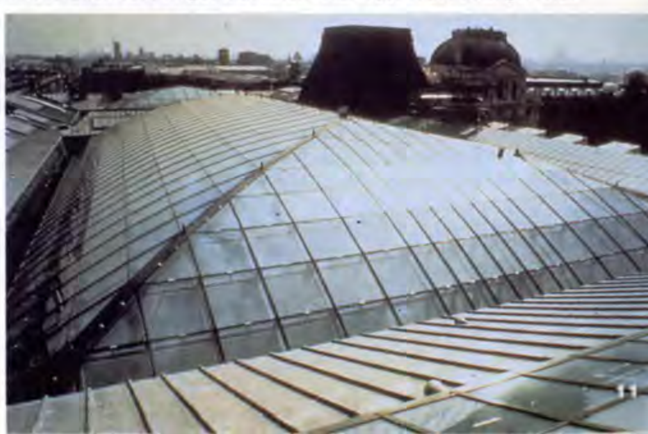
The justification method used fell outside those outlined in the normal French codes used for justifying steel structures. Special technical meetings with the checking authority, Veritas, therefore took place to explain in detail the approach used for structural justification and answer any queries they had. Once convinced of the correctness of the Arup method they were able to give their approval.

Glazing

The glass skin consists of double-glazed units over the grid of tubular steelwork which defines the enclosure geometry. The framing system for the glazing was designed specifically for the project, with special aluminium

◀5. Central clamp node detail to fan-braced arch in Cour Puget.

▼6. Roof of Cour Puget with Khorsabad roof in the background.



◀ 7.
Daylight effect on wall of Cour Marly.

8.
Close-up of skylight louvre sunscreen just visible against the roof glazing.
▼

9. ▶
Typical square gallery: structural crossbeam supports light-directing plaster blades.

10.
Cour Puget.
▼

extrusions being made and cast aluminium pieces used for the framing intersections. An important part of the framing system design was to ensure that any possible moisture due to condensation or accidental leakage in the seals should drain away within the system without dripping onto the floor below. Full-scale mock-ups of the glazing system were assembled to test for construction tolerances and watertightness.

On the inside of the glazing, framed sets of 'paralumes' are set within the open panels in the plane of the steelwork. These hollow aluminium tubes, 32mm in diameter at 53mm centres, serve to filter the daylight entering the courtyards, and provide some diffusion of the light reaching the pieces of sculpture. The paralumes incorporate a form core which helps improve the acoustics within the courtyards by reducing sound reflections.

Design for natural lighting

Criteria

One of the primary reasons for putting paintings on the top floor was to take advantage of natural overhead lighting through remodelling the roof of the building. I. M. Pei and Arups developed a number of criteria for the design of the skylight system. These, summarized below, attempt to balance conservation constraints against viewing conditions, and also address items like cost and maintenance:

- Annual illumination exposure of no more than 850 kilolux-hours
- Filter out harmful ultraviolet light
- Uniformity of light levels over the picture-hanging area of the wall: 2 to 1, maximum to minimum
- Predominant angles of illumination between 25-40° to the vertical
- Floor illuminance less than twice average wall illuminance
- Maintain contact with the external environment
- Simple maintenance, i.e. no mechanical parts
- Save artificial lighting energy and electricity costs.

Some conservation experts recommend an annual illumination exposure level for oil paintings of 650 klux-hours — corresponding to an average illumination level of 200 lux. However, several scientists have shown that 200 lux is too low a light level for many, particularly older, people to perceive detail and discriminate between colours accurately.

Optimum viewing levels, i.e. 1000-1200 lux, were obviously not feasible for conservation reasons, so a compromise of 850 klux-hours (representing an average of average 250 lux) was proposed.

Daylight availability and variation

Before any roof light designs could be considered, the Paris daylight had to be studied, and in particular its variability during the day throughout the year and in different weather conditions. Due to lack of reliable information, external illuminance data for Kew, London, was adjusted for Paris by analyzing the radiation data and sunshine data available in Paris and London. It was found that the difference between maximum and minimum external light levels is around 9:1 during summer, and more in spring and autumn. If both sunlight and sky light are allowed to enter the galleries then variations in internal light levels of a similar order would occur, so the natural lighting system must transmit significantly less sunlight than diffuse sky light. Any direct sunlight landing on the gallery surfaces would be visually very disturbing, so the system is arranged to allow diffused sunlight only to enter.

Layered approach

In order to meet these quite demanding criteria, three distinct layers in the roof of the galleries were conceived:

(1) Glass roof lights: an area equal to about 40% of the gallery floor, and incorporating a UV filtering laminate. A study was made of the colour shift of light passing through normal double glazing with a UV filter. It was found that the iron content of normal float glass causes a slight colour shift towards green, but the additional cost of installing 'white', low iron, clear glass could not be justified.

(2) Sun screen: a matt white eggcrate louvre made of aluminium blades installed directly beneath the glass. Direct sunlight must not land on the paintings at any time, so the dimensions and depth of the screen were calculated for the exact location, orientation, and gradient of each rooflight.

This form of screen is an ideal passive device for removing some of the variability of natural light by transmitting more from the sky's zenith, and less of the highly variable component from the sun.

Arups had initially advocated the use of two or three different interchangeable screens in each gallery — 'seasonally adjusting' the performance of the screen. This would have allowed the galleries to be naturally lit alone for more of the opening hours each year. However, it was decided that a single passive device without mechanical parts or motors was more suitable for a museum of the type and size of the Grand Louvre, and the use of further artificial lighting in winter months was accepted.

(3) Light-directing layer: white painted plaster blades which 'direct' light from the rooflights to the gallery walls. In any top-lit space, the horizontal plane (in this case the floor) will tend to receive more illumination than the vertical surfaces. The form of the plaster blades was developed to allow the wall to receive light directly from the underside of the sun screen, while ensuring that in most cases the floor was obscured from the screen. The blades also ensure that light arriving on the paintings is incident from the optimum direction (25-40° to the vertical).

Only inter-reflected light arrives from angles greater than 40°.

The blades are supported by structural elements designed to cross the roof at regular intervals. Architecturally, the system of plasterwork and beams provides a very dramatic ceiling to the high gallery spaces, as well as concealing banks of fluorescent tubes to supplement the daylight when necessary by illuminating the white sun screen from below.

Contact with the outside

The three layers were designed and co-ordinated to meet the requirements of the eight design criteria described above. The most difficult to achieve was 'maintain contact with the external environment'. The architect was concerned that in many museums with strictly controlled light levels one feels cooped up in an insulated box with no feeling of external light or weather conditions, or even that the space is illuminated by daylight.

Vertical windows are not suitable as a means of providing visual escape because they introduce significant glare and shading problems for galleries. Pei wanted a clear view through the rooflights, with clouds, blue sky, and changes in lighting conditions visible. No diffusing glass was thus allowed, and the sun screens were designed so that persons looking up could see the sky. *continued* ▶

11.
The largest gallery, the Salle Rubens, on the second floor between Marly and Puget.

Computer analysis using finite element techniques

A suite of programs was developed to ensure that the performance of the lighting control system meets the agreed design criteria. A three-dimensional computer model of some of the galleries was constructed. All the model's surfaces, including the 'cells' of the sun screen, were divided into a number of finite elements. Light rays were then cast from each to every other element and to the sky. Checks, of course, were made to ensure an element had an unobstructed view of the other elements or of the sky.

In order to analyze the performance of the first layer — the sun screen — the luminance of the sky had to be represented numerically. Using internationally agreed procedures, the luminance of the sky vault at each angle of view was calculated, and elements on the cell walls of the sun screen assigned illuminance values depending on their view of the sky.

The illuminance of each element on the gallery walls and floor was eventually obtained by calculating the light received directly from the screen and from the plaster blades, and indirectly from the other room surfaces.

Full-scale mock-up

The most extravagant prediction method was to build a full-size mock-up of a typical square gallery in a temporary building in the Jardin des Tuileries, next to the Louvre. All aspects of the architecture were tested in this, from the plaster blades and the sun screen to the colour of the walls and the floor finish. This allowed the architect himself and many of the Museum curators to have a preview of the new galleries and to experiment with the lighting. Oil paintings were brought from the Louvre to add to the realism!

Conclusion

The new Richelieu Wing is now open to the public, and there has generally been a very positive response from the art and architecture world. The courtyards have a very pleasant spatial ambience beneath the new roofs for the public to amble and pause amidst the sculptures. Within the top galleries the true benefits of the natural lighting scheme become evident during brighter days, and a little sunlight brings variation and life to the galleries of the Paintings Department.

Credits

Client:
Etablissement Public du Grand Louvre
Architects:
Pei Cobb Freed and Partners, with Michel Macary
Consulting engineers:
Ove Arup & Partners International Peter Rice, John Thornton, Alastair Hughes, Alistair Lenczner, Etienne Tricaud, Amanda Gibney, Alexandre Cot (design engineers for courtyard glass roofs)
Peter Rice, Andrew Sedgwick, Andrew McDowell (lighting design consultants)
Glazing sub-consultant:
Ian Ritchie Architects, with RFR
Electric lighting consultants:
Claude and Danielle Engle
Steelwork contractor:
Viry SA
Glazing contractor:
Dutemple
Illustrations:
1: Damien Cabiron. 2: Dennis Kirtley.
3: Viry Dutemple.
4, 7, 8: Alistair Lenczner.
5, 9, 10, 11: Peter Mackinven.
6: CEPGL

Oldham Broadway Business Park

Colin Curtis
Nick Fennell
Roger Milburn

Introduction

The Broadway Business Park is a major urban regeneration project some 9km north-east of Manchester near the periphery of Oldham borough, located on 54ha of derelict land with over a century of varied industrial use behind it. Oldham Metropolitan Borough Council bought the site with a view to economic redevelopment, to be funded in part by Derelict Land Grant (DLG) and Urban Programme (UP) monies. In 1989, they appointed Ove Arup & Partners and EGS Design as masterplanners for the development.

The principal aim of the development is to stimulate employment in Oldham by attracting new business to the borough and offering facilities to existing businesses to expand and relocate locally. The first phase of new infrastructure works began in October 1990 and the final phase was completed in December 1993.

The site and its opportunities

The site is divided into distinct areas reflecting its former uses. It is mainly flat except in the north-east, and is bounded to the west by a railway, the north by Grimshaw Lane, and south by the A662 Broadway. This road provides an important link between east Manchester and the M62 motorway.

1. Site history.

The Rochdale Canal runs through the eastern part of the site, where the Chadderton Sewage Works are located. Two large operational electricity switchyards are also present, the 275kV National Grid Whitegate Substation and the 132kV Norweb Station where the power is connected to the distribution network.

A number of aspects enhanced the redevelopment prospects. An undeveloped area this size close to Oldham, adjacent to the planned M66 Manchester Outer Ring motorway, in single ownership, and available not only for DLG and UP grants but also the European Regional Development Fund, obviously had great potential. In addition the Rochdale Canal was there as a potential water feature.

Site history

The first part of Arups' work was a comprehensive desk study into the site history. The area had originally comprised farmland, with a deep valley (Slacks Valley) heading east to west across the northern part; the Rochdale Canal, which opened in 1804, was built on an embankment over Slacks Valley. The Manchester and Rochdale Railway, opened in 1839, was also constructed on an embankment over Slacks Valley and the watercourse running in this valley, Wince Brook, was culverted under both canal and railway.

In the latter half of the 19th century a chemical factory (vitriol works) and the Gibraltar Works (a soap and candle factory) were operating in Slacks Valley — indeed, a signal box on the railway is named 'Vitriol Works'. Tipping of domestic and industrial waste into Slacks Valley to bring it up to canal level commenced in the 1930s and finished about 1975. This was subsequently called the Grimshaw Lane Tip.

In the 1920s, a small coal-fired power station was constructed in the southern part of the site for Oldham Corporation, plus auxiliary facilities such as railway lines, coal stock areas, and wooden cooling towers. By the late 1950s this power station was demolished to make way for the much larger CEGB coal-fired Chadderton Power Station. Again there were many ancillary facilities including extensive railway sidings, coal and ash handling plant and the two switchyards already described. Three concrete cooling towers were located on the east bank of the Rochdale Canal. In 1984 this power station was in its turn demolished to ground level, except for administration buildings and workshop/stores.

◀2. Dredging the Rochdale Canal, June 1993.

3.▶ New road bridge over Rochdale Canal, with canalside features.

To the east of the canal embankment towards the north of the site, the Chadderton UDC Sewage Works were constructed by about 1909. In the 1970s they ceased operation and were partly tipped over with domestic refuse, leaving an area with very variable topography. This is now called the Springs Road Tip.

Oldham Council submitted the desk study report to the Department of the Environment (DoE) to help gain funding for redevelopment. It was well received: and the DoE apparently regard it as a 'model' for this type of report.

Site investigation and ground conditions

Following the desk study, a number of investigations were carried out including:

- checks on chemical contamination of the ground and groundwater of the site as a whole
- assessment of contamination to the Rochdale Canal
- Investigation of landfill gas in the Grimshaw Lane and Springs Road Tips.
- investigations of individual building plots.

The ground conditions succession comprises variable thicknesses of made ground over alluvium locally. Below this is interbedded glacial clay and sands/gravels over unworked coal measures rock. In the Grimshaw Lane Tip, nine types of made ground were identified (the most recent evidenced by Ken Dodd LP covers).

Site constraints

A comprehensive geotechnical desk study clarified the major problems:

- poor access and service provision
- the existing substations, with extensive underground and overhead cables connecting these to the distribution networks
- buried foundations and underground structures remaining from the former power stations
- significant depths of landfill material in both the former tips
- landfill gas generation and contaminated land.

In addition, the generally flat site had few attractive features.

Access and servicing

The only way in was by two 6.5m wide roads from Broadway. These had serviced the eastern and western parts of the Chadderton Power Station and were interconnected at its northern limit. Vehicle access across the central part of the Station was prevented by a retaining wall built to support the sidings for the coal wagons. Drainage was available, but water supplies were only available at the remaining main Station building. A telephone network was installed but this was for the Station's internal use. A gas main crossed the southern part of the site but there was no distribution. There was limited distribution for electrical power as the major demands were within the principal buildings.

Substations, underground and overhead cables

The two substations are the remaining operational areas of the Power Station and are a strategic part of the power supply to Oldham and eastern Manchester. To relocate such important facilities was considered impractical. A further constraint associated with such installations is that large electrical currents can be induced in copper telephone cables should a fault occur in the substations and the energy is passed to the earth. Such currents are hazardous to users and can melt telephone handsets. The area within 40m of a major power substation is known as a 'hot zone' and special protection is required for individual telephone circuits.

Here. there are many underground cables, including 132kV, 33kV, 11kV and 6.6kV circuits, together with numerous telemetry and control cables. In the southern part of the site as many as 20 HV cables are laid in the ground in a single cable route. There are also major cables connecting the substations.

The overhead cables and the associated pylons bisect the site. These are principally the 400kV circuits of the National Grid Company connecting to Rochdale and Yorkshire. There are also a number of 33kV Norweb circuits crossing the site.

Buried foundations and underground structures

The foundations and basements for the power station buildings, the cooling towers, and coal handling plant had been left largely intact. The only available drawings indicated extensive piling and ground floor slabs 700-900mm in thickness. Additionally, the twin 2.5m diameter cooling water culverts connecting the main building to the cooling towers via a bridge over the canal remained.

Areas of landfill

Data collected in the desk study had indicated that, though there were no records of the tipping activities in the former Grimshaw Lane Tip, depths up to 14m could be expected. In addition, at Springs Road tipping had taken place over the abandoned sewage works with no attempt to prepare the location beforehand. This area was left in two distinct portions with approximately 7m difference in levels, separated by Wince Brook.

Development masterplan

From its initial conception Oldham Broadway has been seen as a high quality business park, with Stockley Park as a possible model. The client's objective was to provide $1Mft^2$ ($90\,000m^2$) of development in a landscaped environment. The proposal to construct the M66 Manchester Outer Ring Motorway across the southern part of the site and to provide a major junction with the A662 Broadway would assist these objectives and enhance the Business Park's status.

The masterplan aimed to reduce the impact of the site constraints and maximize development potential. The proposals incorporated the buried foundations wherever possible and tried to avoid conflict with the underground and overhead cables, whilst the hard and soft landscaping was devised to minimize the impact of site features that could not be incorporated into the development or infrastructure proposals. The final masterplan provided a coherent physical framework which underpinned and helped promote future development, but was also flexible enough to adapt to changing requirements.

Water had a strong influence on the masterplan concept; in particular the Rochdale Canal alongside was seen to be a major asset. Its reclamation as an environmental amenity was vital to encourage potential developers to invest in the site. Other separate water features were also proposed.

The masterplan allowed the infrastructure to be phased over three years. The development was divided into five zones in terms of constraints, complexity of engineering and reclamation works, and, significantly, the time needed to prepare a particular zone for redevelopment. Into these considerations was added the arrangements necessary to secure funding.

Road system

The roads for the old power station were in a variable state of repair but it was decided to incorporate as much of them as possible. The substantial existing power distribution equipment made it necessary to compensate by introducing high quality finishes and features. The alignment of the 7.3m wide roads was selected to minimize the effect of existing site features on the development areas, and they were designed with 3.5m wide verges to give a generous feel to the landscaped strip. This verge also provides a corridor for the new services, as well as a facility to widen the carriageway should future need arise. High quality lighting was designed to complement the finishes.

Drainage system

The power station area is generally flat and discharged surface water to the Canal. The design of the surface water drainage was constrained by the outfall levels and the need to achieve minimum pipe gradients with minimum cover depth. In preparing the drainage design, allowances were included to enable future developments to be drained without imposing unnecessary constraints on them. The masterplanning work also identified the minimum amount of drainage works required for the initial development area. Petrol interceptors of up to 30 000 litres capacity were provided on each of the outfalls to the Canal.

Site services

New site services were incorporated into the masterplan to supply the various development plots, which involved considerable liaison and negotiation with the statutory undertakers. The services were planned using the common service trench technique that had proved highly successful on the Salford Quays project.

◀4.
New road alongside canal, looking north, showing block footway construction.

Landscaping

The original intention for the hard landscaping was to use brick or concrete block pavings for the carriageways. However, for economic and technical reasons an alternative was developed incorporating brick block paving for footways, kerb, and channel detail. Red medium-temperature asphalt was selected for the carriageway, the colour complementing the footways. Soft landscaping features including sculptured mounds and water features were planned to provide the site with some visual interest.

Contracts

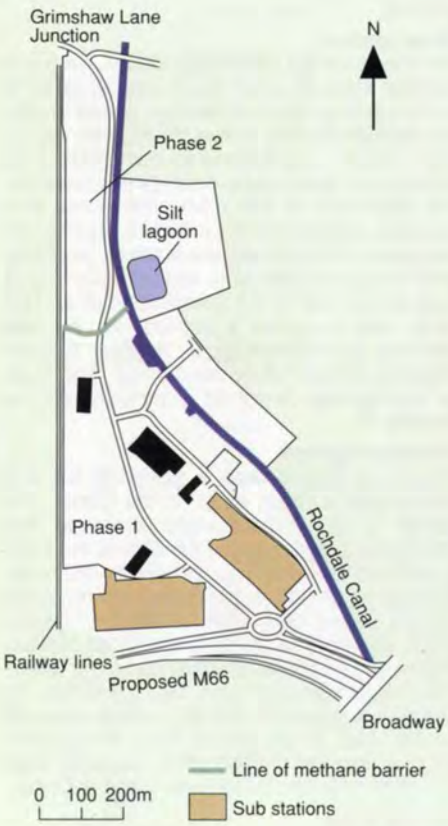
Phase 1 new infrastructure

This began in October 1990, and comprised 860m of new roads plus 400m of resurfaced original road, together with new site services and street lighting. This contract, completed in June 1991, also included extensive soft landscaping of the approaches to the main core of the development, together with a new water feature.

Phase 2 new infrastructure

This contract comprised a further 800m of new road construction with a new 20m span bridge, designed by Oldham MBC, across the Canal. This bridge utilized the old foundations from the cooling water culverts bridge over the Canal. Work began 14 months after completion of Phase 1. The main feature of this contract was the 450m of new road along the edge of the Grimshaw Lane Tip and near the Rochdale Canal. The solution was to partially remove some of the tipped material and effectively float the road construction.

6.
Aerial view showing progress by May 1994.
▼



5. Oldham Broadway: new infrastructure.

The services provided in Phase 1 were also extended in the verges and footways. Drainage for this area of the site was connected to the principal outfalls by an 11m-deep drop shaft, constructed partly in the original Canal embankment and partly in the landfill.

Phase 3 new infrastructure

Phase 2 was completed in April 1993 and Phase 3, completing the primary infrastructure work, began the same month. In this, another 250m of new road was built, of which 130m was along the edge of the Grimshaw Lane Tip. In addition, a new junction with Grimshaw Lane and the northern boundary of the site was constructed, together with a new public car park. All this was finished in October 1993.

Rochdale Canal reclamation

This vital element of the scheme got under way in March 1993 and was completed in eight months. 1.6km of the abandoned Canal was made navigable again, which involved dredging approximately 8000m^3 of silt and depositing it in a specially constructed lagoon. About 1.4km of canal wall were repaired and the towpath refurbished.

To enhance the environmental amenity of the Canal, the reclamation contract included constructing a large basin, a wharf feature, and new access provisions to connect the towpath to the new road overbridge, together with extensive soft landscaping.

Landfill gas barrier works

Following extensive site investigation and gas monitoring, a contract was let to install a landfill gas barrier across the southern boundary of the Grimshaw Lane Tip and a venting facility at the northern end; the work was completed between October and December 1993. It included a 7m deep cut-off incorporating a High Density Polyethylene membrane in a cement/bentonite slurry, together with a stone venting facility. The barrier intercepts the underlying clay stratum to prevent the escape of landfill gas to the adjacent Phase 1 area of the development immediately to the south. Site investigations had shown that the Canal and railway embankments were acting as gas barriers on the east and west sides of the Tip respectively.

Future proposals and summary

The next major area to be tackled is the abandoned Chadderton Sewage Works and the former Springs Road Tip. The proposal is to infill most of this area with surplus excavated material from the M66 motorway construction. Development of this part of the site can then begin. Currently 18 000m^2 of new development has been completed or is currently under construction.

The regeneration of the former power station site demonstrates the importance of a well-engineered masterplan capable of being implemented on time and budget. It is understood this is the first power station site in the UK to undergo comprehensive regeneration.

Credits

Clients:
Oldham Economic Development Unit, Oldham Metropolitan Borough Council (Technical Services)
Architect:
EGS Design, Manchester
Landscape architect:
Oldham Metropolitan Borough Council (Borough Planning Department)
Agent:
Dunlop Heywood
Engineers:
Ove Arup & Partners Roger Milburn, Nick Fennell, Colin Curtis, Richard Summers, Bob Tyson, Jane Collins, Kevin Goodger, Simon Stocks, Mike Andrew, Tony Sumner, Eddie Carmichael, Paul Murphy, Paul Holder, Mark Elsegood, John Bennison, Sheila Nethercott, Mike Wilton
Illustrations:
1, 5: Martin Hall.
2: Norman Edwards Associates (Manchester) Ltd.
3: Peter Mackinven. 4: Bob Tyson.
6: Jefferson Air Photography.

Kansai Airport Terminal, Osaka, Japan

Philip Dilley

The construction of the new international airport is complete, and the terminal building is being opened officially in September of this year.

1. ▲ The 'canyon', a 30m high space for arriving passengers to orient themselves, links the kerbside and station to the main terminal. (Photo: Phil Dilley)

The design of the 300 000m^2, 1800m long terminal building was awarded to Renzo Piano Building Workshop and Ove Arup & Partners International following an architectural competition in 1988. Together with the Japanese architect, Nikken Sekkei, the airport planners Aéroports de Paris, and the specialist advisers Japan Airport Consultants, Arups were appointed to carry out the structural engineering, the mechanical and electrical services, and the fire engineering of the terminal building.

To minimize the effects of noise pollution, the airport is constructed about 5km offshore of the Senshu region on a man-made island. When fully operational, the terminal building will handle 25M passengers per year through 41 aircraft parking spots linked through boarding bridges.

The speed and quality of construction have indeed been impressive. Commencing in 1991, the building was constructed by two separate contracting consortia, led by Takenaka Corp. and Obayashi Corp. The 40 000 tonnes of steel in the main building frame was provided by Kawasaki Corp. and Nippon Steel Corp., who procured a large part of the 10 000 tonnes of roof steel from Watson Steel Ltd. in the UK.

A full article on this project is planned to appear in a forthcoming issue of *The Arup Journal.*

2. ▶ Roof of main terminal building. (Photo: Rory McGowan)

Corrosion: is there a problem?

Graham Gedge

Introduction

There are a number of misconceptions about metal corrosion in construction. It is often assumed that in a given environment it will happen at a uniform rate, thus making corrosion a life-limiting factor. The natural conclusion is that expensive preventive measures need to be adopted or a more exotic alloy material used. Often, however, neither is necessary and a different approach will give a more economic solution.

The corrosion process

The crucial issues are how fast the metal is corroding and whether the corrosion is local or uniform. For example, structural steel in an internal controlled environment will corrode, but so slowly as to be negligible. There is no need to apply any protective coating, which saves costs over the traditional remedy of blast cleaning and coating.

Another example is that of steel piles driven in undisturbed ground. It is often assumed that soil type and chemistry control the durability. However, in most soils these are secondary to the fact that the ground is undisturbed. The oxygen content is low and constant; corrosion rates under such conditions are controlled by oxygen availability and are thus low. Long-term rates are less because corrosion products formed under these conditions act as a barrier to oxygen diffusion and charge transfer. In undisturbed soils rates are low — around 0.005-0.01mm/year — and are tolerable within design limits.

Similar — but more surprising — results can be found in harsher environments, where corrosion is perceived to be far more problematic. Arups were recently asked to assess the likely corrosion of sea water ballast system components that had been operating for 15-20 years in the northern North Sea. It is well-known that steel in seawater corrodes and that the rates can be high — typically 0.3-0.5mm/year. The problem was that this data did not correlate with service experience: at such rates components should have failed within 10-15 years, but they had not. The disparity was because data of this type are based on short-term (6-12 month) exposures and calculated from weight loss.

The disadvantages of this type of testing are:

- It is based on cumulative historical data.
- The data are averaged assuming uniform corrosion and ignoring pitting.
- The rate is assumed to be continuous, constant, and linear with time.
- It ignores the beneficial effects of scale and deposits retarding corrosion.

For continual immersion in seawater, the last two factors are particularly relevant, as build-up of corrosion deposits and marine growths does alter the corrosion rate. Initially, rates are linear and of the order quoted above, but within only weeks they can slow dramatically, and plots of rate *versus* time become exponential. Long-term rates can thus be more realistically assessed in the range 0.1-0.15mm/year, as confirmed by recent published data[1,2]. It was therefore possible to show that, for the components concerned, section loss would have been of the order of 2-3mm over 20 years — not 6-10mm. Thus it was highly improbable that integrity would be affected.

This example shows that, where long-term rate data are available and the macro-environment defined, uniform corrosion is something that can effectively be allowed for in design. However, this is only possible in retrospect after considerable exposure periods, measured in years, in clearly defined environments.

Recently, Arups have taken this approach — looking at rates rather than the simple fact of corrosion — a stage further, and begun to consider less clearly-defined and apparently changeable environments. In these cases, conventional corrosion testing, such as short-term weight loss, is of limited use and one has to use modern electrochemical monitoring techniques. Arups were asked to assess corrosion in the exhaust chimney flues of Pagbilao, a coal-fired power station currently under construction in the Philippines (Fig.1).

Pagbilao

Defining the problem

The exhaust gases are to be expelled via a 210m high slipformed reinforced concrete chimney with two steel flues. The client asked if it was possible to fabricate the latter from plain carbon-manganese steels without either an internal protective coating or a refractory brick lining. Flue gas temperatures were predicted as 110-130˚C and the liner surface could be cooler, although by how much was not defined. The coal source was likely to have significant chlorine and sulphur content, so the flue gases would contain hydrogen chloride and sulphur oxides. Under condensing conditions, below the acid dewpoint, both hydrochloric and sulphuric acid condensates could form on the steel surface.

It is well-recognized that these acids can corrode unprotected steel rapidly — indeed the effect has been likened to pouring watering-cans of battery acid over a car bonnet! Arups' Industrial Engineering group were therefore understandably concerned about the durability of the flues and asked Arup Research & Development to investigate whether a 15-year design life could be achieved without protection.

1. Model of Pagbilao power station.

Conventional solutions

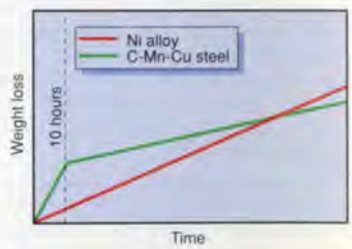
The traditional solution to acid dewpoint corrosion was always to keep the flue gas at 20-30˚C above the dewpoint. This approach was based on short-term exposure tests in bulk acid solutions, which indicated that steels would corrode at high rates at all temperatures up to dewpoint. Following the 1970s oil crises, this approach was increasingly questioned as the temperatures involved (c.150˚C) led to inefficient power generation. This in turn stimulated research into dewpoint corrosion, materials performance, and novel techniques for monitoring and measuring corrosion.

It soon became apparent that the conventional approach was flawed for the following reasons:

- Flue liners were often below the dewpoint temperature.
- Flue liners performed satisfactorily even at these temperatures.
- Short-term tests can be misleading.

The first two of these were directly related to the last, and this is the nub of the problem. Short-term tests in bulk solutions do not normally represent the conditions found in real engineering structures for reasons given above. The inadequacy of short-term tests for corrosion rates is demonstrated in Fig.2, which shows a clear retardation of rate with time for steel, and also that expensive alloys do not always perform better in the long term.

These anomalies were investigated during the late '70s and early '80s as part of a combined research programme called The Acid Dewpoint Corrosion Project[3]. This used recent developments in electronic and corrosion research to monitor corrosion in power generation plants, in real time, using a range of modern electrochemical measuring devices. These had few of the disadvantages of previous techniques, and the great advantage of providing instantaneous corrosion rate data that could be correlated directly with plant operating parameters.

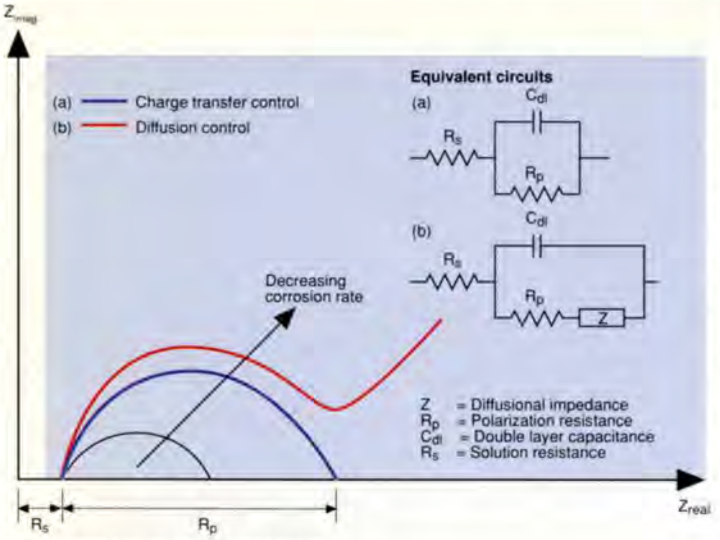


2. Weight loss with time – constant environmental conditions.

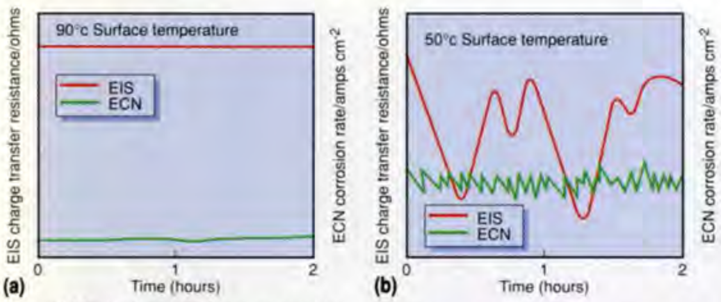
Electrochemical monitoring (EM)

The aim of EM is to provide real-time data on corrosion rates and to link these simultaneously to a series of operating parameters like temperature, pH, flow rate, etc. To achieve this, the corrosion process itself must in some way be monitored, as opposed to its consequences like weight or section loss.

As corrosion is an electrochemical process, it involves the transfer of current as electrons during the chemical reaction. In general, EM aims to measure polarization resistance and thereby calculate a value



3. Equivalent circuits and EIS responses.



4. (a+b) Monitoring – continuous operation.

NOTE: As resistance increases rate decreases

for the corrosion current density (i_{corr}) which can then be translated into a weight or section loss in a predictive rather than reactive way. It is possible to measure i_{corr} directly, but the technique is sensitive because of the small currents involved. Also, such methods only give the current flow and no information on the type of attack.

In power generation the two most widely used techniques are Electrochemical Impedance Spectroscopy (EIS) and Electrochemical Noise (ECN). EIS is based on the concept that a corroding interface can be represented by a relatively simple equivalent electrical circuit (Fig.3). The response of such a circuit to a small amplitude input (either voltage or current) at various frequencies allows individual components to be evaluated from a complex plane plot of impedance, the low frequency intercept being a direct measurement of polarization resistance. However, the EIS plot shape also gives other information about the corrosion mechanisms: a simple semicircle with two intercepts on the real axis indicates a reaction controlled by metal dissolution. Alternatively, a plot with a low frequency tail at 45° to the real axis, and no intercept, indicates a reaction controlled by diffusion; typically this would be found for corrosion of steel in water which is controlled by oxygen diffusion (Fig.3).

A metal corroding in an environment has associated values of both corrosion potential and current, often assumed be defined and precise: for example, steel can be described as corroding in seawater with a potential of -450mV. In reality such a value is better regarded as a mean about which both current and potential vary by small amounts, typically microvolts and nanoamps — this is referred to as 'noise'. By monitoring simultaneously these small changes, i_{corr} can again be calculated from Ohm's law ('current equals electromotive force divided by resistance'). The monitoring and subsequent analysis of these changes is referred to as ECN.

In-service monitoring

When used in power station flues, EIS and ECN provided much information about the corrosion that was going on and why carbon-manganese steel can perform satisfactorily. More importantly, they also showed the importance of environmental changes on corrosion and how good plant/process management could minimize the effects in a much more controllable manner than was previously the case.

It was always assumed that corrosion rates in flues would be similar to those in bulk acids of a similar concentration to that found in condensable films inside flue liners. Indeed, monitoring showed this to be the case for an initial short period, after which the rate fell significantly. EIS attributed this to an increase in charge transfer resistance indicative of a build-up of protective scale on the steel surface. This observation was confirmed at flue surface temperatures as low as 90°C — well below the flue gas and dewpoint (Fig.4a).

Despite this apparently satisfactory conclusion, anomalies still existed. It was known that certain areas of flues could suffer severe local damage. It was also known that some plants suffered greater general corrosion rates than others. It was shown — again using EIS — that local damage would occur in areas that were excessively cooled due to air ingress or poor insulation. In such locations, metal surface temperature could fall locally to as low as 40-50°C (Fig.4b). This is in the region of the hydrogen chloride dewpoint. As hydrogen chloride condenses, the charge transfer resistance falls because of a change in the nature of the surface scales. This results in the corrosion rate increasing as hydrogen generation is facilitated, and the rates tend to reach those of bulk solutions.

The difference between plants was traced directly to the way in which they tended to operate. Those operating more or less continually on base load suffered little serious attack, whilst those operating on a more cyclic loading condition were more severely damaged because of higher corrosion rates associated with plant start-up and shut-down (Figs.5 & 6). During start-up, steel is attacked by acid condensate for a while until a protective scale can form. During shut-down the scale breaks down and also spalls as the flue cools. At the same time the environment changes to that of the prevailing external conditions. This usually means relatively high humidity that can itself corrode steel, but the rate is also increased by activating trapped acid on the surface.

It is therefore possible to predict with confidence that even in an apparently unfavourable environment conventional steels can perform satisfactorily. It was concluded for Pagbilao that the flue design (to avoid cold spots) and plant operation (to avoid stop/starts) were far more influential in controlling corrosion than the environment itself. It was also recommended that the installation of EM could be used to both confirm this and optimize plant operation.

Conclusions

EM represents the leading edge of assessing corrosion rates and clearly shows that, by understanding environments and reactions, corrosion — particularly the uniform type — can be more understood. And Arups' work in other areas has shown that understanding corrosion rates can lead to more economical design solutions.

The use of EM is an emerging technology that need not be restricted to the power industry. Its use to predict corrosion is obviously an advantage to be exploited but represents a limited use of the technology. Because EM, particularly ECN, monitors the material behaviour in real time and is extremely sensitive to small environmental changes, the possibilities for these techniques are significant.

For the first time, there is no longer an excuse to accept corrosion as an inevitable destructive force. It is now possible even to use it as a surrogate, employing its real-time measurement to control plant plus process operation, to improve operating efficiency, programme maintenance, optimize materials performance, and when things do go wrong to explain why. This is all possible because of the technique's extreme sensitivity in detecting corrosion well in advance of conventionally-defined physical symptoms.

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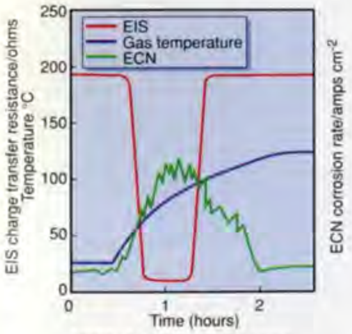
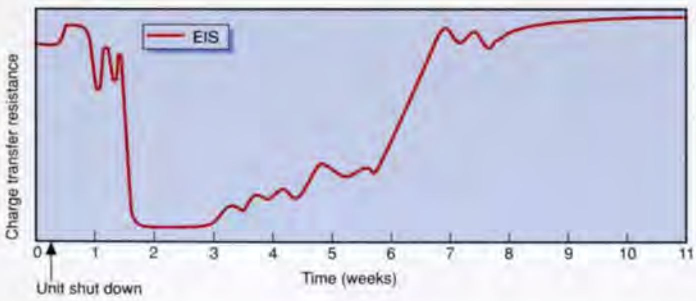
Graham Gedge is a metallurgist in Arup Research & Development.

Illustrations:
1. Photo: Ove Arup & Partners
2-6: Martin Hall



NOTE: As resistance increases corrosion rate decreases

◀ 5. Monitoring – plant start up.



▲ 6. Monitoring – plant shut down.

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