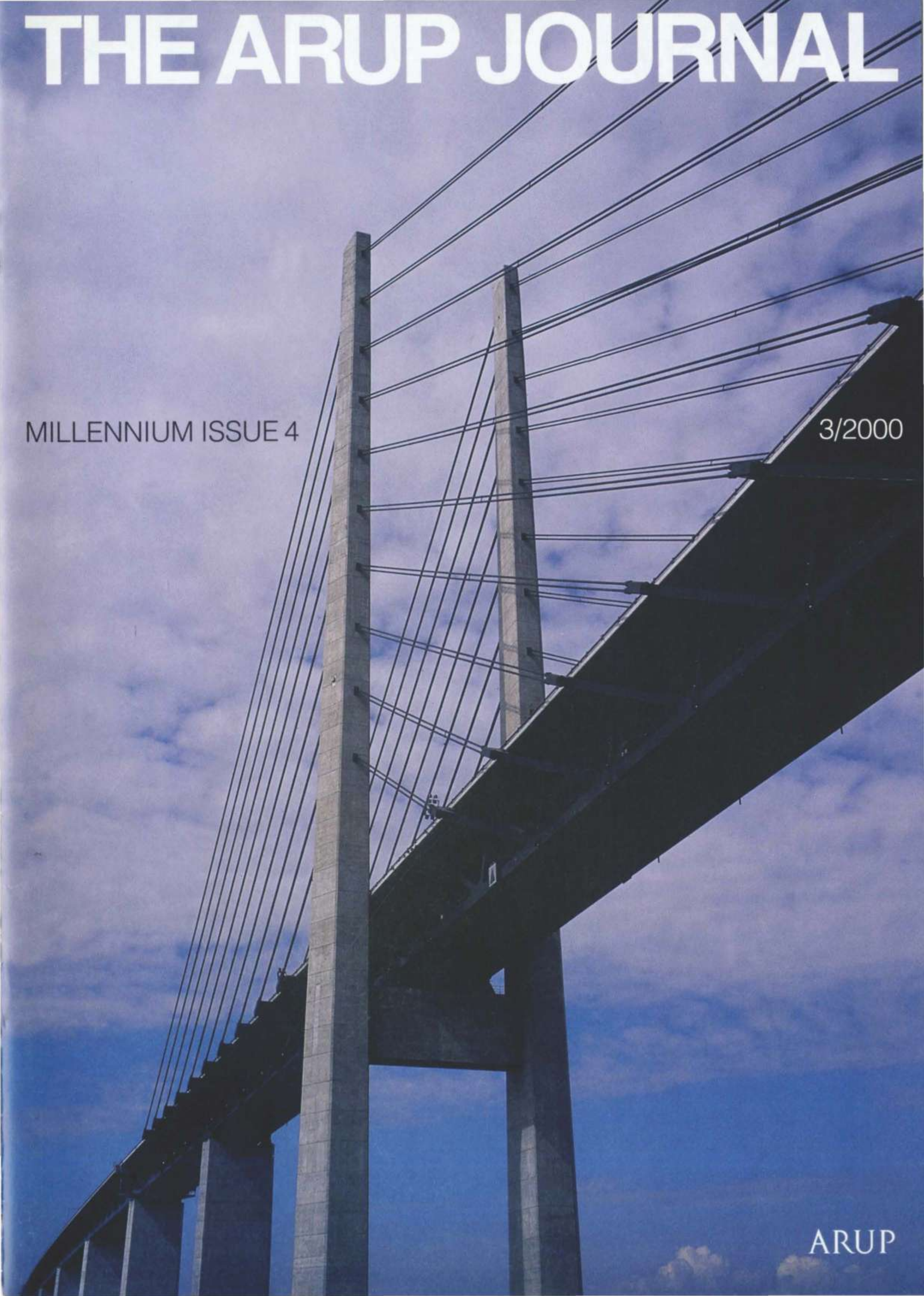
THE ARUP JOURNAL



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Front cover:
The Øresund Bridge (pp20-27) (Photo: Jørgen Nissen)

Back cover:
Tate Modern, London (pp3-11) (Photo: Dennis Gilbert)

Arup is an organisation of designers. With its constantly evolving skills, it works for local and international clients throughout the world.

We shape a better world.

Editorial

This edition of The *Arup Journal* opens with one of the firm's most notable recent building engineering achievements, the renovation of Bankside Power Station as the Tate Modern art gallery in central London (pp 3-11). The remainder of the issue is mainly concerned with a wide variety of Arup infrastructure projects. Arup's principal involvement in Tate Modern has been with all aspects of the gallery's engineering design, but the firm's initial connection with the project was to advise the Tate on the implications of developing various sites for it. Besides being the new home for Britain's national modern art collection, Tate Modern forms a major contribution to local urban regeneration.

A few miles upstream, at Docklands in east London, Arup acted as environmental and engineering consultants to the London Docklands Development Corporation for a different kind of urban regeneration project, the creation of 9ha of new urban parkland from a highly contaminated brownfield site in the Borough of Newham (pp32-34). Camden in north London, by contrast, is normally perceived as one of the most capital's most affluent Boroughs. Nonetheless, it has a wide variety of social problems, and Camden commissioned Arup to prepare a comprehensive Urban Regeneration strategy to address many of these (pp28-29). Also in Camden is an Arup renovation project as contained and site-specific as the Urban Regeneration strategy was broad-based - the design of state-of-the-art replacement high speed lifts for the 190m BT Tower (pp30-31).

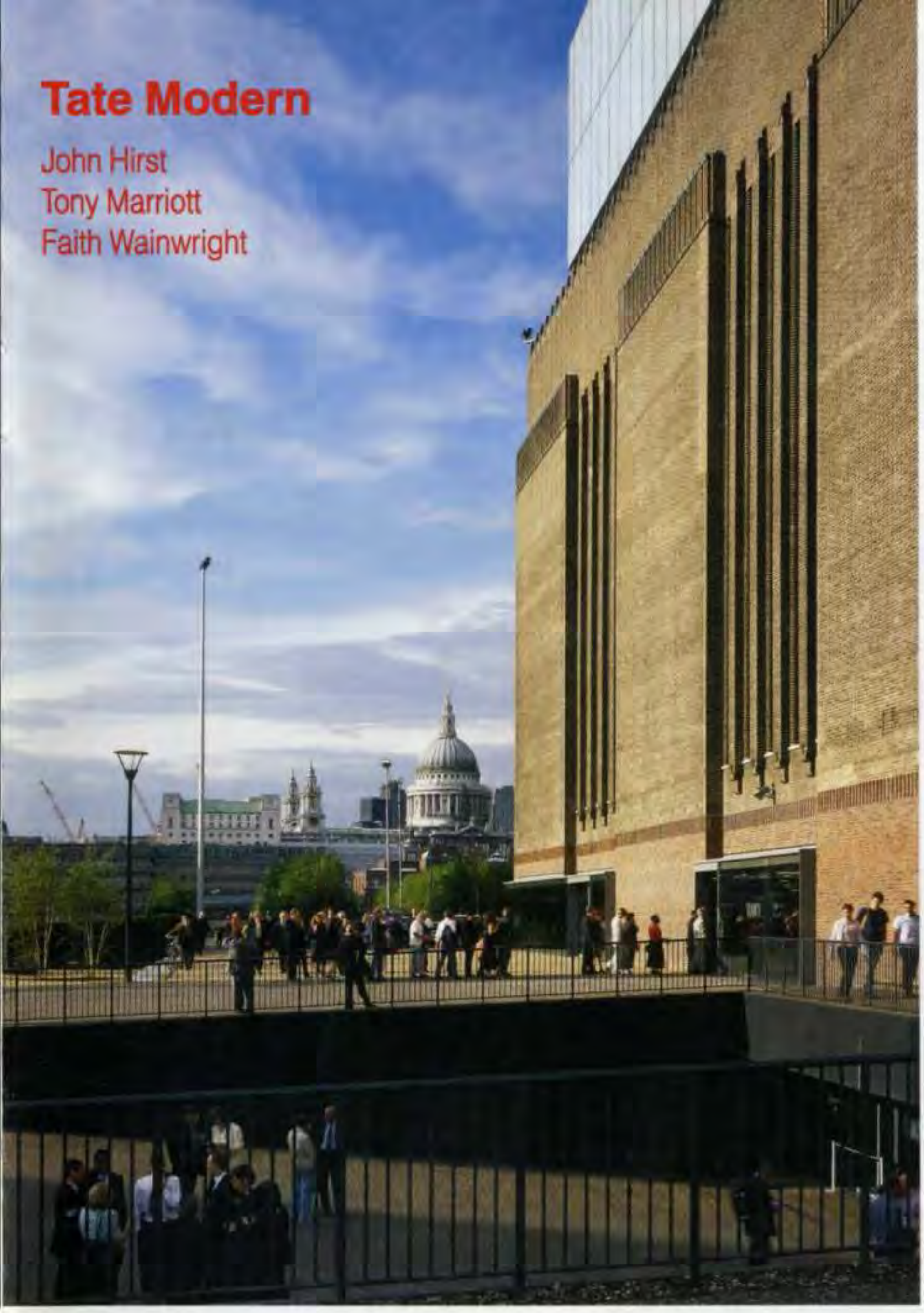
Transportation is a key aspect of infrastructure development. This edition contains examples of Arup's recent work in the fields of air, rail, and road transport. At Johannesburg International Airport, the South African practice Arup (Pty) Ltd engineered new retail 'nodes' for passengers (pp12-13), designed to be prefabricated offsite and wheeled into place within extremely tight weight, space, and time constraints.

Arup is active in much rail-related work. West of London, Reading Station is a significant bottleneck on routes out of Paddington, and the firm was asked to undertake a feasibility study of how it could achieve its potential as a major node in the national rail network, as well as becoming a high quality interchange between different modes of transport, and a focus for other local development (pp14-15). In the European context, far-reaching schemes are in progress to arrest the decline of rail freight compared with road, and the EC commissioned Arup to look at the feasibility of extending the Trans European Rail Freight concept into Central and Eastern European countries (pp16-17). And the 8km Arup-designed road and rail bridge - a steel and concrete embodiment of Denmark and Sweden's desire to facilitate links between them - now stands in the waters of the Øresund (pp20-27).

Elsewhere in this issue Duncan Michael, Chairman of Arup's Trustees, looks at trends and strategies in achieving 'globalisation without economic colonisation' (pp16-17). A large technical consultancy like Arup can clearly deliver many skills reliably and speedily towards shaping a better future. A specific example is in Bangkok, where a million of the inhabitants are now benefiting from yet other Arup infrastructure skills through the Yannawa project, which is providing major environmental improvement in the form of proper wastewater collection and treatment (pp35-41).

Tate Modern

John Hirst
Tony Marriott
Faith Wainwright



1.
The west elevation and entrance ramp to the Turbine Hall.

Introduction

Tate Modern was opened by HM The Queen on 11 May 2000.

Created from the shell of a disused mid-20th century power station at Bankside on the Thames in central London, the new Gallery is undoubtedly one of the most important public buildings to be realised in the United Kingdom at the end of the 20th century. It has received almost universal acclaim and has been compared favourably with major modern art galleries around the world.

The public has responded enthusiastically, with 1M visitors in the first 47 days, compared with the predicted 3M per year.

The design development involved consultation and collaboration between artists, the client including curators, and the design team. The design works with the grain of the original building, which has been used sympathetically but has not been over-protected.

Much more than a conversion and renovation has been achieved: a true transformation of Giles Gilbert Scott's Bankside Power Station has taken place.

As signalled by its name, Tate Modern is devoted entirely to contemporary art, enabling the Tate to display a significant proportion of its collection, but the project has also created more than a magnificent new gallery. Fulfilling part of the vision of the Tate's Trustees, it has instigated a regeneration of the urban area around it. The Millennium Bridge (to be featured in a forthcoming *Arup Journal*), contributes to this and will provide a key link across the Thames between northern Southwark and the City.

Background

The Tate considered several potential sites, including Vauxhall near the existing Tate (now 'Tate Britain'), Jubilee Gardens, and through to the Greenwich peninsula. Arup advised on the implications of developing some of these. However, they wanted a central location, easily accessible to the public, and providing a focus for urban regeneration. Bankside Power Station gave this opportunity. The Tate also consulted a wide range of artists about the nature of the galleries they would want their work displayed in, and most expressed a preference for those created from existing buildings.

Before committing to Bankside, the Tate commissioned studies of the location and condition of the building, to check that their positive attitude to the site was valid and that its potential could be realised. Arup examined the engineering aspects during 1993, and in the following year, the Tate arranged an international design competition for the 'Tate Gallery of Modern Art'. The brief included: 'To give the building a public and civic sense, it will need to be opened up, with large-scale interventions within and through the structure, so as to establish connections between the interior of the building and the river, and vertical links between the basement and the roof.'

The competition was won by the Swiss architectural practice, Herzog & de Meuron, whose work until then had been mostly in northern Germany and Switzerland. They chose in their submission to have the old turbine hall as a single cathedral-like volume, with galleries built within the northern part of the existing building where the boilers had previously been. They also showed the turbine hall as a cross-roads for both east-west and north-south routes through the building, with a monumental ramp from the west entrance. Much of this concept has been carried through and more may be achieved in future development.

Bankside Power Station

Site history

The site has a history of industrial uses dating back to the mid-1700s. There was a coal-fired power station on the eastern part before the new oil-fired station was constructed - in two phases, commissioned in 1953 and 1963. The coal-fired station continued to function during the first phase building. In conventional fashion, the plan was divided into three with the boiler house in the north, the turbine hall in the middle, and a switch house to the south - this remaining operational today.

The main plant in the boiler house and turbine hall was generally independent of the structure, which reduced the complexity of retaining most of the existing envelope. However, the flue gas washing structure was integral with the building structure and contributed to the overall stability system.

The basement varied in depth, generally 8.5-9.5m, with mass concrete retaining walls approximately 2-3m thick. The foundations were pads and strips constructed on London Clay. The chimney has an independent stability system, comprising K-bracing between the four corner columns, and is supported by a cellular raft which incorporated the cooling water intake system.

Water for the station was taken from the Thames via a jetty on the south bank immediately north of the station, and used for cooling as well as gas washing. The cooling water was distributed within the station via a system of culverts before discharge via a tunnel from the east of the station to the river's north bank.

Investigating the existing construction

When Bankside was first identified as a possible site for the new Tate, it was disused, leaking, in need of fabric repair, and still contained all the plant from its operational time. Initial investigations involved extensive visual surveys of the brickwork and opening it up in several places, mostly by rope access from roof level, to assess the condition of the steelwork. Also, samples were retrieved to analyse mortar composition and sulphate content. The brickwork had been constructed without joints, and there were many vertical cracks in places consistent with being caused by movement.

The asphalt roofing had broken down and flashings over brick piers were conspicuously missing, so water penetration into and through the fabric had been severe.

2.
Exhaust air from the galleries is used to moderate the Turbine Hall environment. Glazed bay window enclosures provide lighting to the Turbine Hall.

3 below:
The shop viewed from the lowest concourse.

The concrete roof was found to be cast in situ for the first phase and in precast panels for the second phase. These, together with elegant lattice precast roof panels with inset glass blocks, were investigated for carbonation, chloride content, and cover, to assess their potential for further years' service.

Concrete taken from cores was also petrographically examined. Though access difficulties limited initial examination of the concrete roof, it was clear enough that the glass block rooflights could not be retained because of significant carbonation and the onset of corrosion.

The main concrete roof areas were found to be in better condition, but a subsequent, more comprehensive survey showed that maintenance would still be needed once the building was completed. For this reason, and the risk to the public from spalling concrete, it was decided to replace the roof slabs.

To reduce the deterioration rate of the structure and fabric of the building, interim measures were undertaken, which continued during the contract for 'deplanting' the power station. The Tate took possession of the site on completion of these works. By now the volume of the boiler house and turbine hall was clear, apart from the frame of the gas-washing plant, which had been retained for stability reasons.

Overall concept of the new Gallery

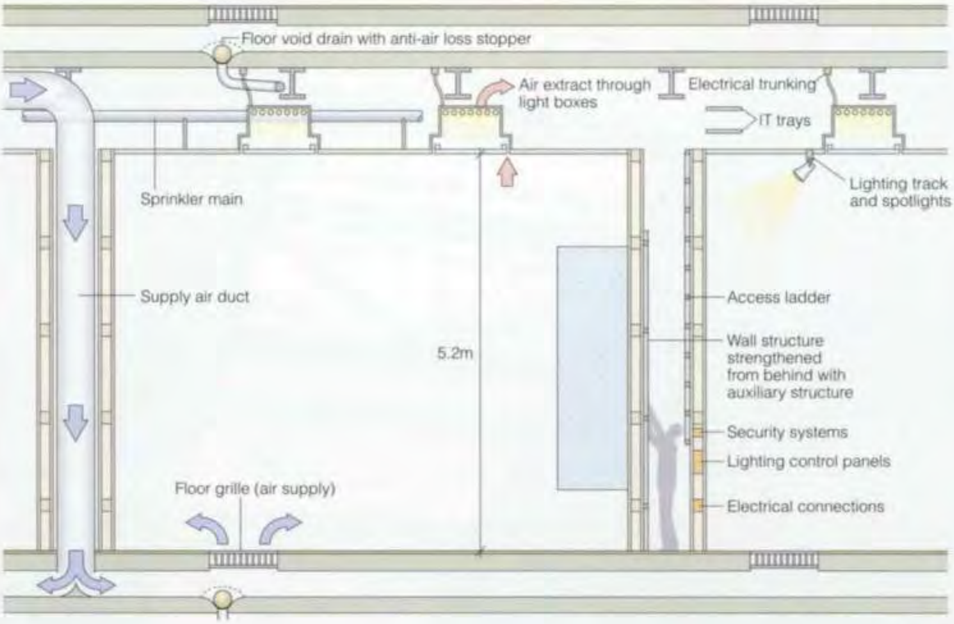
The combined turbine hall and boiler house was a huge volume, 160m long, 54m wide, and 34m from basement to roof. Herzog & de Meuron's approach was to locate the main galleries plus support facilities over seven Levels within the boiler house space. The turbine hall remains - an impressive entrance volume to the Gallery. People enter from the west, and from the riverside, north of the Gallery. The west ramp takes visitors down to the entrance of the gallery levels at Level 1. From the north, people enter each side of the chimney, through to a bridge in the turbine hall, where a stair leads to Level 1. Disabled access is via lifts. From the entrance, escalators take visitors to three levels of galleries. Above these, they emerge above the parapet of the original building to encounter magnificent views over St Paul's Cathedral and the City of London. The glass-clad structure along the top of the building known as the 'light beam' provides natural light to upper galleries and also contains a new members' room and a restaurant, plus air-handling plantrooms. The light beam also signals the enormous changes that have taken place within - at night the internal lighting expresses the variety of functions added to the upper levels, but with a certain degree of abstraction.

4.
Clerestory lighting from the light beam to level 5 is configured to provide an even glowing surface.

5 right:
The interstitial space of the light beam, showing feature lighting and lighting control blinds.

6 right:
The scale of the Turbine Hall has been used to provide a dynamic entrance space.


Tate Modern: Collection 2000
in association with
Galleries
The Unilever Series: Louise Bourgeois
Sponsored by Unilever
Shop



7 above
The principles of gallery servicing.

8 right:
Inside a display wall.

The challenge was to provide 28 000m^2 of new, highly serviced floors within the existing enclosure, but discreetly engineered to achieve the aspirations of the client and architect. The building's function is to display modern art - hugely variable in its characteristics, many of which influenced the design. This was a particular challenge as the galleries will contain works not yet created!

The works vary enormously in size; some are very big and heavy; some use unusual materials or electronics that need to be connected to support systems; many are highly sensitive, particularly to variations in environment; all are valuable, and some are priceless. Art works are framed or unframed; sculptures are displayed with or without plinths; objects are displayed on walls, on the floor, and hung from the ceiling. The response to these issues was to provide rooms of differing sizes and proportions, but all with a clean and uncluttered appearance so that visual distraction is minimal, and with the potential to adapt room layouts in the future.

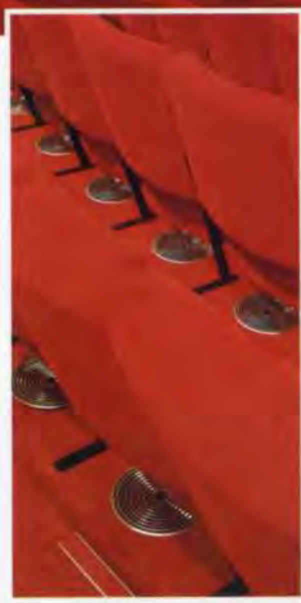
As well as these functional aspects, there were the normal issues of capital costs, cost in use, programme, buildability, and safety; although discussed in relation to separate disciplines for convenience and intelligibility, the engineering aspects were developed in concert with the architectural design.

A key component of the design was the concept of a double-skin, wide cavity display wall. The cavity is accessible and, as well as leading to the ceiling space, provides a route for air distribution to the floor plenum for the displacement air-conditioning system. The accessible cavity also allows Gallery staff the facility to enhance the load capacity of the walls for displaying particularly testing wall-mounted exhibits. The walls are restrained by the ceiling grid and this enhances the accessibility of the ceiling space.

The lighting system - expressed as uniform panels of light - is designed to avoid veiling reflections which would obscure the detail of exhibits and to provide an even distribution of light on display surfaces. The spacing of the lights is such that, if a wall was removed, the space left is on the lighting grid. Similarly, if any new wall is built, its top will co-ordinate with the gap from removing a luminaire. This reduces to a minimum disturbances from adapting wall and, therefore, room layouts.

9.
The café at level 2.

10.
The Starr Auditorium is located at Level 2 (ground) adjacent to the café. A full range of audio-visual facilities, including those for celluloid film, are provided.



11.
Air is supplied to the auditorium via floor diffusers.

12 below.
Air supply to the galleries is via cast iron grilles.

Some equipment above ceilings needs regular inspection. Wherever possible, this is close to walls, so that it can be accessed by climbing up inside a wall, but some had to be located further than a safe stretching distance from walls. The only elements in the ceilings are the lightboxes and these have to be the access into the ceiling. They were designed with removable sides and top, and all equipment needing servicing or inspection is located within arm's reach of the nearest light box. The ceiling is, therefore, kept clean and clear of any access panels.

The structural grid co-ordinates both with that of the retained building envelope, allowing the lancet windows to be unobstructed, and with the room layouts, so that vertical structure is mostly concealed within the display walls.

Mechanical engineering

The criteria for air-conditioning the display spaces became apparent almost from the outset. The obvious one was to maintain conditions suitable for displaying and preserving artefacts with very widely varying population densities and lighting arrangements. Not quite so obvious was the need for robustness to cope with the ways the art would be displayed. For instance, some or all the air supply diffusers in a space might be blanked off if they were considered a distraction to the optimum display of the art. Energy efficiency and simplicity in operation were high on the priority list, as was the need for maximum stability of conditions in the event of plant failure.

After analysing several systems, we chose low velocity, low level air supply through grilles in floors with extract through the lightboxes and into the ceiling void to minimise room effect of the lighting. This system has the fewest active components at high level and thus requires minimum elevated access for maintenance - beneficial in terms of costs, lack of disruption to the use of the space, and minimum visual distraction. The system is also energy-efficient and robust, as the supply air temperature is only slightly below room temperature. Outside air can thus be used for cooling in much of the year. This system can also make best use of the thermal inertia of the structure in the event of short-term cooling plant failure.

The down-side of the system is the need for a greater floor zone to accommodate the under-floor supply air plenum and the greater capital cost of the raised floor. However, the system was clearly preferable overall.

The supply grilles, to maintain visual vestiges of the industrial building, were to be large, heavy and as far apart as possible. Bearing in mind that some, perhaps 5% in any display suite, would be blanked off, extreme cases were agreed with the client, and extensive computational fluid dynamics (CFD) studies made of them. The system could cope, at least in theory, with great variations in visitor loading and with fairly cavalier treatment of the air supply grilles. Now that the building is in operation, with visitor numbers far more than predicted and extensive blanking of supply grilles, system performance has proven more stable than the studies indicated: minor revisions to the control settings have further improved it.

Air-handling plants at Levels 1 and 7 draw outside air down the cores, mix it with recirculated air as required, and heat or cool it to maintain gallery conditions. The supply air is ducted through the cores to primary distribution ductwork high in the display suites on Levels 3 - 5, from where it is ducted vertically within the display walls to the plenum beneath the floor.

Each suite is served by two air-handling plants rated at 50% of maximum duty, so that one can be shut down for planned maintenance without loss of condition in the space and to give cover for plant failure. These plants contain activated carbon filters as well as the usual air-conditioning components. Cost-in-use comparisons were made between (a) 'free cooling' using maximum outside air but exhausting the carbon filters more rapidly, and (b) using minimum outside air to extend the filter life at the cost of additional mechanical cooling. The decision was to minimise mechanical cooling and thus reduce energy consumption.

Extract air is drawn through the lightboxes into a ceiling plenum and thence through ducts in the cores to the air-handling plants. These ducts also form smoke extract shafts with the smoke being handled by separate fans. The normal extract from the Level 1 plant is discharged into the turbine hall, an untreated space. The discharge air tempers conditions in the turbine hall, which would otherwise be fairly similar to those outside.

The same system was adopted for the concourses, with air supply through the sides of the escalator enclosures, through stair risers, and also through floor grilles. Art handling areas were treated to the same filtration standard, but through high level supply and extract. The restaurants, kitchens, education areas, and other back-of-house spaces were provided with comfort cooling.

The central plantroom is beneath the switch house, about 6m below the level of the internal road. This contains the gas-fired boilers, water heaters, and associated pumps and controls, with the flues being taken through the edge of the turbine hall to roof level. It also contains the chilled water pumps and controls. Various forms of heat rejection were considered and extensive studies carried out to assess the viability of cooling by groundwater. Although this would have had environmental benefits, the cost of the necessary wells, pumps, collection pipework, and filters was prohibitive and the idea reluctantly rejected.

All other forms of heat rejection are bulky, and choosing where cooling towers or dry air coolers could go was a matter of finding the least intrusive solution. In the end, air-cooled chillers were chosen and located behind the building, immediately above the central plantroom. They are acoustically treated to minimise disturbance to the residential buildings across the road.

Heating and chilled water is piped from the central plantroom through a tunnel beneath the turbine hall to the base of the risers to serve air-handling plant at Levels 1, 6, and 7, fan coil units, and other heat emitters. The central plant area also contains the electrical intake and substation.

13.
Air handling plant at level 1.

Electrical engineering

Tate Modern is no stranger to electricity, having previously been a power station. Once the energy transformed in the boiler house from fuel to heat was used to generate electricity in the huge turbine hall, which was then distributed to the outside world via the switch house. In its new incarnation, this flow is reversed.

The switch house still contains a major London Electricity substation at ground level, serving much of south London and the City. A high voltage supply drops to the basement level of the switch house from this substation, to provide the Tate's intake. The associated main switchroom then routes much of the power through a services tunnel below the turbine hall, before rising to serve the galleries in risers within the boiler house.

Standby power for life safety services, and other essential systems including the art handling lifts, comes from a diesel generator installation, designed to be upgradeable. This would allow some of the display suites used for travelling exhibitions to have their environmental systems backed up. Much of the art work in these exhibitions is loaned, often with conditions attached. The Tate wished to be able to respond to any move in the art market to attach absolute conservation conditions to such loans, at some point in the future.

The desire to minimise the visual impact of anything not itself art affected the design, selection, and positioning of all services in the display suites, from smoke detectors to exit signs and floor grilles. The biggest effect of all can be seen with the lighting system - the lightboxes and skylights.

The lightboxes on the third and fourth floor galleries incorporate lighting tracks for feature lighting to suit particular exhibitions. As already noted, visually the lightboxes are glowing planar surfaces, flush with the ceiling, but much lurks behind the surface. The glass front panels of the lightboxes are hinged to allow for re-lamping, and the internal panels and lamp assemblies are also demountable for access to the extensive ceiling void behind. This allows maintenance of void smoke detectors, installation of new cables, testing of smoke dampers, etc.

On Level 5, what at first appear to be more light-boxes are in fact skylights to allow daylight into the upper galleries, controlled automatically by blinds. Here, and at the vertical windows around the perimeter of the Boiler House, blackout facilities are provided to stop light reaching art works when the Museum is closed.

Digital lighting control makes exhibition arrangements flexible, with the fluorescent lamps in the lightboxes dimmable to 1% of normal output to suit curatorial or display purposes. It also allows any of the possible room configurations (several display walls are temporary) to be individually set up by curatorial staff standing in the Gallery using a plug-in scene setter. In the skylights and clerestories, two dimmable circuits serve each display space.

Different colour-temperature lamps on each circuit allow the apparent colour emitted to be adjusted, supplementing and following the changing colour of daylight throughout the day. The lighting control system also allows several pre-sets to be programmed for each space - configured to display periods, evening functions, cleaners' lighting, and security patrol levels, for instance.

The emergency lighting also has a central control system. Experience of this type from German projects guided the choice of a system with central testing facilities and lamp failure detection. This gives significant maintenance benefits to the client, particularly as so many lamps are high up.

14.
The main stair links all concourse levels and incorporates sheet steel and unfinished oak treads. Lighting is concealed above the stained oak handrail.

Structure

Selecting the frame and foundation systems depended on several issues, the most influential being the original building's massive concrete pad and strip foundations, breaking through which would have been costly in both time and money.

Also, it was impossible to locate piles to best suit the new frame, as the existing foundations to the central line of retained columns and to the perimeter retaining walls had to continue to function. Piles would also have had to be located within the mass retaining wall, necessitating expensive transfer structures to avoid columns in gallery spaces. A raft over the original foundations and ground bearing slab was thus the preferred solution.

A steel frame complements a raft foundation, as loads from structure self-weight are reduced. The frame could also be constructed within and tight to the retained envelope of the power station. Fabrication of the frame proceeded in parallel with other construction, allowing a programme advantage. A 7.77m east-west structural grid was selected to match that of the existing columns, leaving the original lancet windows clear of vertical structure. It also left brick panels between the window sets clear and allowed openings in the external wall at various levels.

Columns from the new frame are seated either directly on the raft or onto the top of the mass retaining walls at Level 2. In the latter case, resistance to splitting or shear failure in the concrete had to be provided by tensioned bars in holes drilled through the retaining walls of the stanchion bearings. In addition, new concrete pad-stones were cast to deal with local bearing issues.

At foundation level, the raft was cast into pockets cut into the retaining wall, to allow the retaining walls and raft to behave monolithically under vertical load.

Before construction began in the boiler house, the frame of the flue gas-washing plant, remaining after deplanting, had to be removed. As this helped stabilise the remaining structure, something else was needed until the new was in place.

15.
Central boiler room.

Fire engineering

Chris Barber

General

At first sight, Tate Modern appears difficult and complex in terms of fire safety, due to the size and drama of the large spaces, especially the Turbine Hall. In reality, it was possible to exploit the size, and identify solutions relative to the component parts of the building.

Defined by height, it is classified as a Section 20 building under local London Building Acts; this essentially deals with the use of sprinklers, ventilation and fire brigade access, and facilities, and in general the design complies with Section 20. For means of escape, automatic smoke detection and voice alarm are used throughout the building. The initial agreement with the local authority is for simultaneous evacuation following an in-built delay period to allow investigation and confirmation of a real fire incident.

The facilities available allow the Tate to further manage and stage evacuation with the agreement of the authorities.All other aspects of the scheme meet the requirements of the Building Regulations, except that sprinklers are of the pre-action type.

Turbine hall

Because of its volume and height, the turbine hall was approached as a covered street. It was agreed with the local authority that the natural ventilation at roof level would be over-specified relative to the normal requirements for an atrium or similar space. Make-up air is provided by approximately 20m² of opening doors at ground level but with 100m² opening at the roof.

There are no sprinklers in the turbine hall but there is a fire main and hydrants for fire fighting. There was no need to compartment the hall from other parts of the building, the use of sprinklers and obviating the need for this. The existing wall to the south of the hall provides a substantial fire separation to the existing operational LEB sub-station. The structural frame on the north side of the turbine hall, where exposed, is protected by intumescent paint.

Shop and ancillary areas

These, including the lecture theatre, cafe, restaurant, workshops, etc, are separately compartmented, but not from the turbine hall, due to its classification as a street. They are provided with sprinklers and mechanical ventilation in accordance with the requirements.

The concourse levels

These provide access to galleries and restaurant facilities via escalators and a main stair. They form a single compartment through all floors, separated from the galleries by fire-resistant construction. There is nominal ventilation at high level to suit only a potentially small fire. Fire loads are controlled by the need to maintain clear and generous circulation space for the general public.

Galleries

The gallery spaces are relatively cellular with several fire-resisting security doors completing compartmentation. The environmental wall inside the original walls was also fire-rated so as to allow a vertically ventilated cavity between the new and existing construction, while maintaining fire compartmentation.

The Gallery sprinklers are of the pre-action type, which reduces the risk of accidental leakage and water damage which concerned curators (the same applies to any area where art work is displayed, stored, or handled). Smoke ventilation is via the ceiling plenums and make-up air is supplied from the floor grilles.

Refuges for the disabled are provided in the escape and fire-fighting stairs, augmented by the arrangement of small gallery rooms with direct access to stair cores. The rooms are effectively treated as extensions to the stair lobbies.

16.
The platform stair provides access to the gallery entrance from the north entrance.

17.
Gallery rooms are 'clean' and visual distraction is minimised.

Two temporary stability towers were therefore erected outside, one each side of the chimney, to avoid compromising other construction activities and access inside. The towers were linked to the boiler house roof trusses, from which the roof slab had already been removed.

The new frame is mostly conventional composite steel construction, though the design needed to take into account several issues including:

- movements, particularly between the retained envelope and the new frame
- the need to minimise intrusion of the vertical structure into the usable spaces
- provision of high load capacity for the gallery floors.

For the floors up to Level 4, the 30m deep north-south space is divided into three approximately equal zones, resulting in an internal grid of approximately 7.77 x 10m.

The four service cores utilised for stability are each located in the central 10m bay. At Level 5, transfer beams accommodate a change in grid in the central bay to 7.2m - 15.7m - 7.2m, allowing wider central gallery spaces rising uninterrupted through Level 6 and side-lit via the light beam. The clear height in these spaces is approximately 10.4m. The side galleries at Level 5 - reduced in width relative to the other floors - are also naturally lit via rooflights.

The gallery floor system has to carry heavy loads, provide a sufficiently airtight plenum for air supply, and give separation between fire compartments at different levels. A proprietary raised access floor above the structural slab, as often used for an air plenum, was unsuitable here because of the high loading requirements, particularly from point loads. The best solution comprised a lower floor supporting a second, upper floor 460mm above, with a plenum between them. The lower floor is typically a 130mm composite concrete slab supported by and acting compositely with steel beams, whilst the upper floor system comprises a 110mm composite concrete slab, typically spanning 2.59m onto steel sections which, in turn, span between posts on the lines of the steel beams to the lower floor. Holes for air supply and outlets are framed locally. To accommodate the runs of high-level ductwork and other services within a minimum zone, the steel beams supporting the main frame are notched at their ends.

At Level 5, to gain sufficient headroom under the retained turbine hall roof trusses, the entire central area of steelwork was lowered some 460mm and the upper slab omitted to allow for cantilevered balconies. Air is supplied in this area through stair-risers and panel balustrades.

On the gallery floors, the wall to the turbine hall is glazed, which allows the visitor splendid views into this enormous space. On Levels 3 and 5, this experience is enhanced by balconies, which cantilever into the turbine hall at up to 25m above the ground slab.

A movement joint is provided through the superstructure frame on all floors, at about 50m from the west end. This has the benefit of reducing stresses within the cores due to temperature-generated movements and, more particularly, reducing the relative movements between the internal frame and the retained external envelope. The new frame was subject to varying external temperatures during construction, but will be stable in use. However, the external envelope will continue to respond to external temperatures, so it was decided to provide translational restraint perpendicular to the wall only. Thus, the walls remain free to move relative to the frame in a line parallel to the walls.

There is no connection between the new frame and the wall in the north-east and north-west corners, allowing the wall to warp in response to its own temperature variation.

The building's stability is provided by conventional bracing within the four cores. The movement joint is designed to allow shear loads in the north-south direction to be transmitted, whilst allowing east-west movement.

The project required areas of the existing envelope to be opened up for both visual and access purposes, principally above the north entrance, through the west retaining wall and via the glazed openings to the ground floor cafeteria. Each required a particular approach.

The areas of the original envelope around the north entrance on each side of the retained chimney were replaced by new construction, with the new brickwork supported on a framework hung from the floor structure, to achieve horizontal glazing clear of vertical structure.

18.
Level 5 concourse and bay window balcony overlooking the Turbine Hall.

The west entrance is formed through the original 2m thick mass concrete below the retained brickwork. This required careful sequencing of work, to maintain both vertical and lateral support to the base of the brickwork during execution.

The new openings to the cafeteria were formed without the use of independent support. Small openings were formed into which galvanised stools were installed to carry the vertical load; a horizontal slot was then formed, leaving the load-bearing stools in place. Reinforced concrete beams were cast around the stools and, finally, the now redundant brickwork in the area of the opening was removed.

Floor loading criteria

It was clear that 'normal' recommendations for imposed loads would not meet the needs of the Tate, especially bearing in mind the nature of contemporary art; the fact that it is unpredictable requires the design to be as flexible as possible, to accommodate as much as possible. To achieve an appropriate level of flexibility in use, combined with economy of construction, a loading study was undertaken.

Acoustics

Chris Manning

In general, acoustic controls are discrete, and based on conditions measured at existing galleries. The sound insulation between galleries is potentially very high because of the deep cavities, but open communication between galleries is the limiting factor. Acoustical absorption has been introduced to some areas at high level, with finishes selected to visually match the rest of the room.

The auditorium was designed for conferences, lectures and films; it is thus well insulated from the surrounding spaces and designed to provide good conditions for natural and reinforced speech and for AV and film sound.

One main challenge was to control the noise from the equipment in the LEB sub-station. Early in the project it was identified that the bank of electrical transformers would remain in active use well beyond the opening date.

These emit a characteristic hum at 100Hz, which was transmitted to the old turbine hall and boiler house through the structure of the buildings and their foundations. Since the retained sub-station and the proposed gallery areas could not be structurally separated, a programme of vibration isolation of the transformers was embarked upon. The objective was to reduce transfer of the audible hum to the galleries, whilst recognising that a residual presence would always remain in the area of the turbine hall closest to the transformers.

Because the transformers are tied in to the National Grid, individual ones could only be isolated during periods of planned maintenance outages. This meant a complex programme of prioritising the oldest and noisiest transformers, sine the overall programme would not permit all of them to be isolated before opening to the public.

This 'transformer muting' programme is well advanced, though the full benefits will not be realised for some time.

Transformer hum has been successfully controlled to the point where it is not a feature of the acoustic environment within the galleries. The residual hum in the Turbine Hall is audible but not the dominant feature it was before the muting programme commenced. It has been commented that this is totally in keeping with the context of art gallery in a former power station, one journalist even thinking the engineers had deliberately introduced it!

20.
View across the River Thames to Tate Modern on Bankside.

19.
One of three similar chambers which contained oil tanks for the power station. These may form a future phase of Tate Modern.

The Tate provided information relating to both wall-mounted and floor-mounted exhibits that had proved difficult in the past, and criteria were derived for both. The floor loads from exhibits were considered in combination with 'people' loads and wall loads. The floor load design criteria were developed iteratively in consultation with the client. The process involved postulating a series of criteria and then testing them for individual exhibits and combinations of exhibits.

For the upper floor slab, the client required high local capacity, and two criteria were developed. First, the capacity of the art handling lift was agreed as 10 tonnes. A concentrated load of 25kN was, therefore, agreed, which allows for the load of 10 tonnes to be taken equally on four points. The requirements of exhibiting 'Mother and Child, Divided' by Damien Hirst informed the second, and a uniformly distributed load of 20kN/m^2 was adopted.

For the lower floor slab, the provision of circulation space and the relationship between exhibits and walls were taken into account.

For the vast majority of 'difficult' exhibits, identified by the Tate, a combined imposed load of 9kN/m^2 was found to be adequate. To provide additional flexibility, the Level 5 galleries were designed for an imposed load of 12kN/m^2. This was particularly influenced by one piece: 'Untitled' by Ruckreim, which comprises four pieces each weighing 2 tonnes exhibited against a wall.

Credits

Client:
The Tate Gallery

Project manager:
Stanhope Properties Ltd

Architect:
Herzog & De Meuron Architekten

Associate architect:
Sheppard Robson

Multi-disciplinary engineers:
Arup Chris Barber, Mike Banfi, Bob Barton, Olly Base, Norman Beaton, Fergus Begley, Rowena Blood, Anita Bramfitt, Jonathan Brecknell, Mike Buglear, Lee Carter, Bob Clapham, Paul Coe, Mark Collier, John Coppin, Martin Crichton, Arfon Davies, David Deighton, Liam Delaney, Nigel Dore, Anthony Dunnings, Tony Fitzpatrick, Joe Flores, Andy Foster, Michael Francescon, Asim Gaba, David George, Barrie Gould, Jenny Greaves, Fiona Green, Danny Hall, Martyn Harrold, Inka Heile, Colin Hemmingham, John Hirst, Jenni Innes, Ron Jacobs, David Johnston, Alex Jones, Bernard Killick, Florence Lam, Rosemary Law, Keith Lee [deceased], Ruth Lees, Catherine Leggett, Martin Lesh, Gerry Loader, Duncan Macintyre, Chris Manning, Tony Marriott, Fergus McCormick, Tristan McDonnell, Grant McInnes, John Miller, John Morgan, Doug Moulton, Philip Mulcahy, Duncan Nicholson, Richard Nowicki, Kiran Patel, Jackie Perryman, Alan Reading, Robin Riddall, David Satchell, Andy Sedgwick, Robert Senior, James Shaw, Jeff Shaw, Julian Smith, Rob Stewart, Glen Swinney, Paul Thompson, Mark Towell, David Trelease, Malcolm Turpin, Jean-Paul Vélon, Faith Wainwright, Sean Walsh, Colin Whewell, Jo Wilms, Ray Young

Construction manager:
Schal Construction Management Ltd

Cost consultant:
Davis Langdon & Everest

Landscape architect:
Kienast Vogt

Illustrations:
1-6, 8-20: Dennis Gilbert
7: Martin Hall

Johannesburg International Airport: new retail nodes

John Abbott Damane Hlalele John King

Introduction

After an intensive two years' design and construction, the three new retail nodes and associated decline ramps at Johannesburg International Airport's International Terminal were opened to departing passengers at the beginning of December 1999. This exciting project arose out of the need by ACSA (Airports Company South Africa) to upgrade the terminal, the most important element being to provide a large area of world-class duty-free shopping.

1 top:
The completed nodes in position.

2.
Partially cutaway model showing steel structure.

However, the space needed for this was not available within the existing building so the architect, RFB Nagar, proposed extending it into the triangular clearance space between parked aircraft on the apron.

This world-first idea produced an extra 7000m² of trading and circulation space at departures level, 10m above ground, with minimum interference to airport operations at apron level.

Arup's involvement, first as structural and façade engineer and later as project manager for the steelwork phase, grew from a small appointment to advise the architects on some special glazing in another part of the building.

Structural design

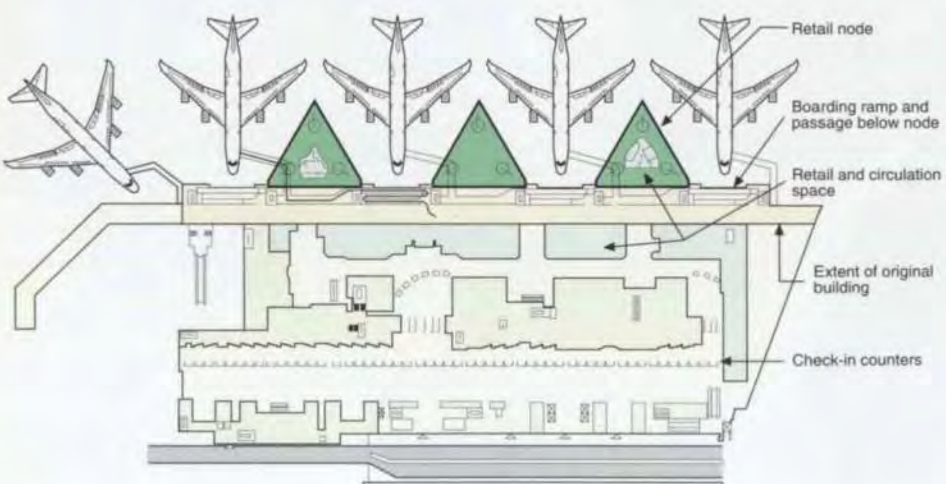
To minimise disruption to the operating airport during construction, Arup proposed at the outset that the nodes and airside corridor structure incorporating the decline ramps be built of steel, prefabricated off-site, and wheeled into place overnight. After all, the components couldn't weigh more or be bigger than a Boeing 747, which the airport tractors move around every day.
As it later transpired, when steel fabricators and main contractors Girder Naco were appointed, this was the same method they had used some 10 years previously in constructing the original airside corridor structure, and the wheel sets used then were still available.

Each triangular node is 800m² in plan at departure level and 960m² at roof level. Each stands on three inclined tubular steel columns (508mm diameter x 32mm wall thickness), which then project above roof level to provide the hanging points for 90mm diameter Macalloy suspension rods supporting the perimeter of the structure at both levels. In this way the fully glazed perimeter at departure level is kept column-free, enhancing views from inside.

The three-column arrangement also minimises the effect of the structure on the service operations at apron level. For safety, each steel column stands on a conical concrete plinth, 3m high and 2m wide at its base, designed for possible accidental vehicle impact. Both the roof and the departure level floor are of composite construction with steel beams, permanent steel shuttering, and concrete slabs. The airside corridor structure is also in composite steel, designed in conjunction with Girder Naco for prefabrication.

A further aspect of the design is the façade, which on the triangular nodes consists of 7.0m high glass walls on the two outward faces, giving departing passengers spectacular views of their aircraft at close quarters. The glazing mullions are elliptical, using aluminium extrusions specifically developed for this project and reinforced with steel plates internally to minimise their size. High performance South African-made glass is used, incorporating a heat-rejecting film imported from California to control solar gain from low-level morning sun. The glass is also lightly tinted to control glare levels inside the retail space.

For protection against a fire on the apron, the outside of the glass can be drenched with water, supplied by a pipe and nozzles down the edge of the mullions. All steelwork is protected by intumescent paint.



3.
Plan showing nodes against the terminal building.

4.
3D rendering of aluminium glazing mullion.

5.
Large sub-assembly of node roof being lifted into place in the temporary construction yard.

6.
Blue-painted steel temporary carrying chassis beneath node.

Keeping things moving

In the efforts to limit disruption, particularly to the high revenue 'contact stands' for aircraft parked against the terminal, the construction yard to assemble the steel structures was established about 1km north of the airport building. At the same time, preparatory work in the existing structure required much of the existing airside corridor structure to be removed. Again to minimise disruption, this was done - after the 10pm flight left - at night, working above a pedestrian tunnel constructed within the existing building to allow continued passenger movement during the rest of the day. So exacting were ACSA's requirements for the waterproofing and finishes of this temporary work that most passengers were unaware of the construction happening just overhead.

Similarly, the piling and concrete plinths on the apron had to be constructed in overnight occupations, with a further ACSA requirement that no soil or rubble be allowed on the apron during the day. This meant that before first light the apron had to be cleaned and the works closed up each morning with temporary steel plates.

While the foundations were being installed, all the structural steelwork was being prefabricated in a carefully programmed operation at Girder Naco's works in Wadeville and then delivered to the construction yard. In a series of dramatic night operations, 30m transfer girders of up to 70 tonnes were 'walked' across from the construction yard by two cranes and then lowered into position between existing structures with little clearance each side. These were followed by 16m x 10m sub-assemblies of roof beams and cantilevering girders, from which the floor and ramp structures were suspended leaving the busy service road below free of columns. By far the most spectacular night moves were of the 210 tonne triangular nodes, which were fixed onto a temporary transport structure with 48 wheels and towed along the taxiways by two aircraft tractors. The progress of this juggernaut was monitored against programme as it followed a pre-determined surveyed route. The first night move took all the available time, moving into position just as the landing lights of the 5:30am flight from Singapore came into view.

By the next move the operation was successfully completed by 2am, with the huge structure moving at walking pace for much of the way.

Once in position, the steel structures were finally levelled and the concrete decks cast. For completion of the nodes and airside corridor structures, building materials were lowered via the roof to further reduce interruption at ground level. This way, the façades were installed and internal finishing completed in time for the programmed 1 December 1999 hand-over.

The success of this exacting and exciting project depended on teamwork within the large design team and with the contractors. It is a project that all can be proud of, and was recently honoured with 'overall winner' awards from the South African Institute of Steel Construction, as well as the Association of Architectural Aluminium Manufacturers of South Africa.

Credits

Client:
Airports Company South Africa

Architect:
RFB Nagar

Structural and façade engineers and project managers:
Arup (Pty) Ltd John Abbott, Keith Baker, Rod Benard, Gaye D'Alton, Damane Hlalele, John King, Neil MacLeod, Gary Noca, Ash Parshotham, Radivoj Sendic, Errol Shak, Frans Simak, Craig Thompson, Vernon van der Merwe

Main and steelwork contractor:
Girder Naco

Associated structural engineers:
Goba Moahloli & Associates

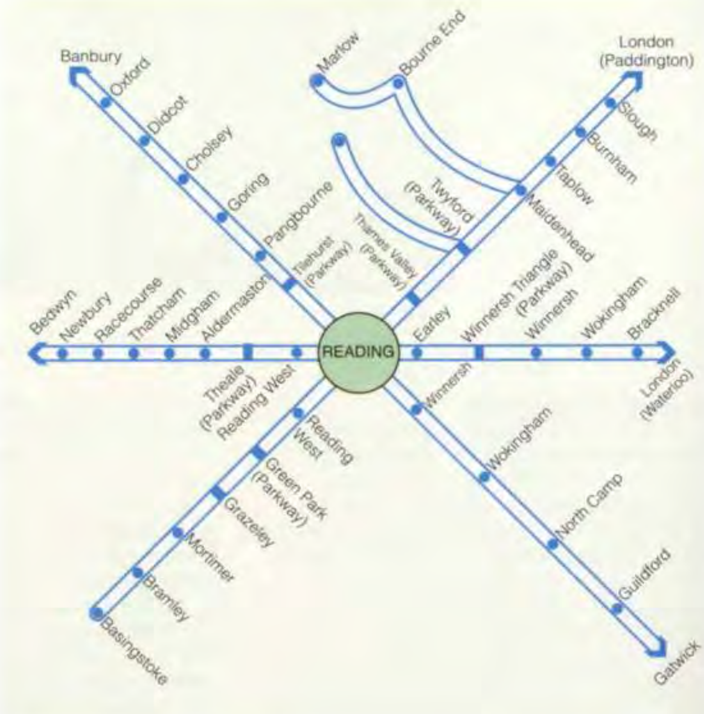
Illustrations:
1, 2, 7: John King
3: Claire Noble
4. Radivoj Sendic
5, 6: Spencer Erling, Girder Naco

7.
Second node being moved from construction yard to final position.

Reading Station

Adrian Gurney Malcolm Simpson

1.
The grade II listed façade of Reading Station.



2.
Rail services linking with Reading.

Introduction

Reading is at the centre of a rapidly growing sub-region of south east England, and the Borough Council is aiming to meet the growing demands made on it in a sustainable way - by increasing use of public transport, walking and cycling, and providing for substantial development within the town centre. At the same time, both Railtrack, the UK national rail infrastructure company, and the individual transport operating companies (TOCs) are increasingly aware that Reading Station forms a significant bottleneck on the routes out of Paddington (Fig 2), particularly with the conflicts of movement with rail traffic from the Midlands to the South Coast, and growing freight travel. Also, the passenger facilities in the Station are inadequate.

The Reading Station transport feasibility study was undertaken to establish the scale of change required for Reading Station to achieve its potential as:

- a major node in the national network, becoming an international gateway to the UK and Europe, for the Thames Valley region
- an integrated part of the town and its sub-region, enabling high quality interchange between different modes of transport, and with easy access for pedestrians and cyclists and the mobility-impaired
- the focus of a major development project that will help to shape the character of the area and its links to the river and beyond.

The client body, led by Reading Borough Council and Railtrack Great Western, also included First Great Western, South West Trains, Thames Trains, Virgin Trains, EWS Railway, First Beeline, Reading Buses, and Readibus. This was to be an unusual study - both in terms of the mix of interests in the client body and in the range of Arup skills needed to meet the brief. Particularly significant was the extent to which Arup was able to elicit the agreement and enthusiasm of the full client body, as solutions were developed.

Rail traffic

One of the first tasks for the Arup team, led by Arup Transport Planning, was to clarify the need for change to the Station layout and design. High levels of growth in demand were reported by the TOCs. National and local transport policy and road traffic congestion are expected to drive continuing rail passenger growth, so ambitious targets for future growth were considered appropriate.

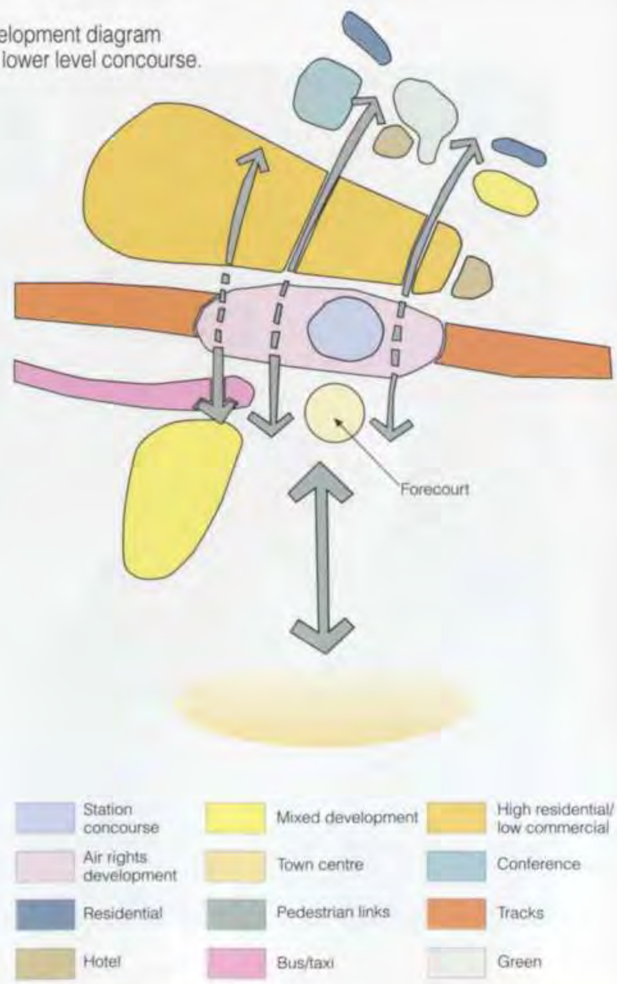
It was agreed by the TOCs that a passenger growth forecast of 7% a year should be used, and freight traffic is expected to double in the next 10 years. Arup assisted Railtrack in testing the 7% pa growth forecast on Railtrack's Vision model, to explore whether their currently planned improvements could provide the operational capacity needed. This growth level showed a predicted average delay of four minutes per train by 2011, and this was considered unacceptable by Railtrack.

Major changes to the track layout at Reading Station, giving a step change in capacity, therefore need to be provided to cater for expected growth in rail traffic before 2011.

Rail capacity strategies

Arup examined various ways to add greater capacity without increasing the Station envelope, since it was considered important that the opportunities to knit together the areas around the Station should not be compromised by increasing the width of operational land. Options include re-opening the freight underpass, using crossover junctions to the east and west of the Station to allow the mainline tracks to run to the north (thus limiting conflicts of movement), and linking the Wokingham and Berks & Hants lines, which currently terminate at opposite ends of the Station. A major implication of these changes is that the existing concourse south of the Station will not be able to serve new platform arrangements efficiently - since the main passenger movements will be to and from platforms on the north side. A new concourse either above or below the tracks will be needed.

3.
Development diagram with lower level concourse.



Passenger interchange

Discussions were held with TOCs who expressed concerns about provision:

- within the Station for general passenger movement, information and ticketing arrangements, platform facilities, and mobility-impaired access
- for external interchange with bus; air link coach; taxi; cycling; drop-off, short-stay and long-stay car parking; and mobility-impaired and pedestrian facilities.

Surveys were carried out to clarify the numbers of passengers moving within the Station, and the number of interchange movements at the Station; particular congestion points were identified. Outside the Station the weekly pedestrian flows were as high as those in parts of the town centre. The substantial increase in passenger numbers noted above, together with a significant increase in development in the area, will mean that the Station needs to cater for double the existing pedestrian flows by 2011.

In addition there will be much increased demand for interchange facilities in and around the Station. If the aims of national and local policy to increase the use of sustainable modes are to be addressed, then there will need to be transfer of use from the car, particularly to bus and cycling. This will mean maintaining long-stay parking at its current level; providing adequate short-stay parking facilities; giving taxis closer pick up / drop off points; and integrating bus operations and cycle parking with the Station.

Town centre and riverside

One of the main tasks for the Arup team was to establish the opportunities presented by potential change at the Station for Reading centre, which has some 260 000m^2 of retail floorspace (including 'The Oracle' opened in 1999), about 25 000 jobs, and a residential population of 21 000 within 2km radius. The population and number of jobs within the wider catchment area of the centre is expected to continue to grow rapidly over the next 10 - 15 years.

The brief here was to explore how the town centre could be expanded to the north to balance the shift to the south brought about by the opening of The Oracle, and provide for the increasing pressure for development - particularly by overcoming the current severance between town and river.

Changes proposed by Arup will create opportunities to improve links through the Station between the centre and the river, with the concourse placed more centrally in any new Station design, either above or below the railway (Fig 3). Pedestrian and cycle routes through from the centre towards the river would be improved as part of the wider development.

The improved links would substantially increase development opportunities north as well as south of the Station.

New concourse and interchange

To explore the relative merits of an upper or lower concourse across the full width of the Station, Arup undertook a range of work covering:

- engineering and geotechnical issues related to constructing the different concourses
- impact on original Station building (listed grade II), and opportunities and costs of relocation
- development opportunities at the Station and in the wider area related to the different concourse levels
- timetables for the delivery of the different concourse designs
- costs and funding opportunities.

Improved interchange arrangements have been proposed:

- bus station on the southern side to serve the centre as well as the Station
- removal of general traffic from the roadway south of the Station to improve pedestrian links into the town centre
- greater integration of buses, air link coach, mobility bus, taxis, and pedestrians with the Station
- provision for car drop-off, taxi set-down, pedestrians, and cyclists to accommodate approaches from north, east and west of the Station.

Fig 4 illustrates possible interchange arrangements combined with the lower level concourse.

Conclusion

The study has clarified that:

- There is urgent need for a step change in capacity if Reading Station is not to become a major bottleneck on the rail network before 2011.
- The changes at the Station can also provide for improved interchange, particularly with buses and for pedestrians and cyclists, so that Reading can function more sustainably.
- There is opportunity for major development, with improved links between the riverside and Reading centre.

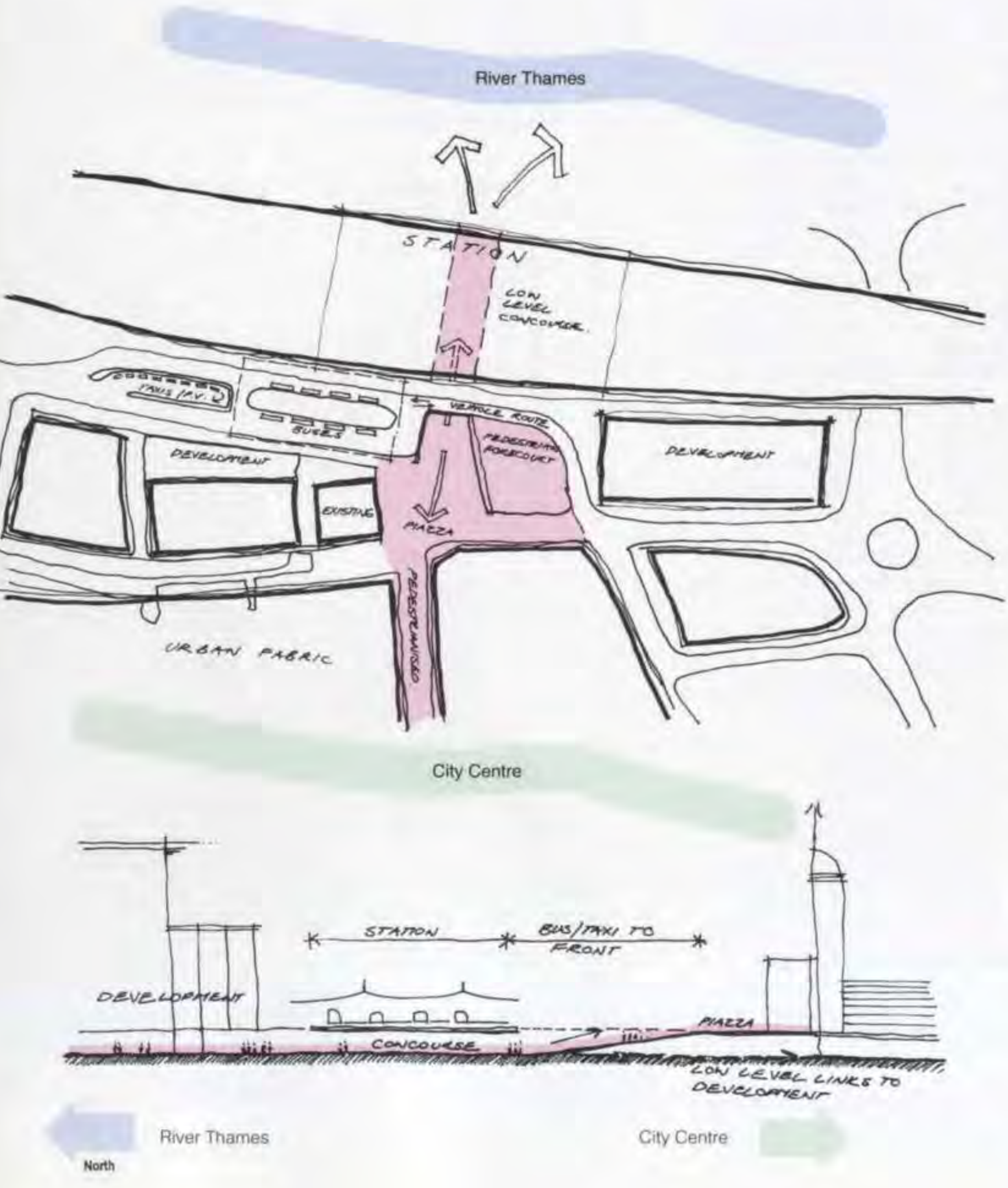
The findings of the study were presented to a briefing session for the Department of the Environment, Transport and the Regions, Government Office for the South East, the South East England Development Agency, and the shadow Strategic Rail Authority, as well as the full client body. At this meeting the uniqueness of the enterprise was welcomed, with its involvement of all the interested parties in examining long-term proposals of strategic importance to the region. The proposed changes at Reading Station have been placed, because of the study, at the top of the planning agenda of those bodies that will ensure implementation.

Credits

Clients:
Reading Borough Council
Railtrack Great Western
First Great Western
South West Trains
Thames Trains
Virgin Trains
EWS Railway
First Beeline
Reading Buses
Readibus

Consultant:
Arup John Cavill, John Cripps, Leszek Dobrovolsky, Adrian Gurney, Steve Harrison, John Henry, Alain Marcetteau, Andrew Martin, Strachan Mitchell, Miles Price, Chris Rooney, Harry Saradjian, Malcolm Simpson, Peter Speleers, Emine Tolga, Suzanne Walker, Paul Whitehouse

Illustrations:
1. Reading Borough Council
2. Peter Speleers
3. Emine Tolga
4. Leszek Dobrovolsky



4 left:
Interchange with lower level concourse.

Extending TERFFs to Central and Eastern Europe

Ed Humphreys Ian Birch

Introduction

In November 1998 an international team led by Arup Transport Planning was appointed by the European Commission to look at extending to Central and Eastern European countries (CEECs) the Trans European Rail Freight Freeway (TERFF) concept introduced in the European Union the previous year to improve attractiveness of international rail freight. The contract was part of the Phare Multi-Country Transport Programme. 'Phare' means 'Poland and Hungary: Action for Restructuring the Economy', an EC initiative begun in 1989 when these two countries detached from the Soviet bloc. The programme rapidly extended to other CEECs.

Arup was responsible for the project management in a team including Prognos of Basel, Regional Consulting of Vienna, Transman of Budapest, DHV (CR) of Prague, the two Dutch firms DHV (BV) and Railplan, and several individual rail / freight experts. Local consultants were appointed in seven of the Phare countries.

Rail freight in the EU

Between 1970 and 1994 rail freight in Western European countries lost half its market share, mainly to road haulage, bringing the greater external costs associated with road transport, ie accidents, pollution, and congestion. Over this period the total freight market grew by 70%, but the rail market decreased from 283 to 220bn tonne kms and the rail share from c32% to 15% (Fig 2). Even in long-distance freight, where the economics are more favourable to rail, it lost market share. Although much of this decline stems from changes in economic activity, other factors can be influenced by EC policy, such as national policies which disadvantage rail, and organisational inertia within national railways.

Problems with rail freight

The reasons for rail freight's decline relate to most aspects of quality of service and can be worse for international transits involving more than one railway administration. The European Conference of Ministers of Transport lists the main problems as:

- technical incompatibilities
- differences in organisation between national railways
- financial constraints and issues at national level
- balance of payments considerations
- inter-railway communication and load tracking.

A train from Rotterdam to Budapest, for example, has to cross at least three railway borders using track electrified to three or four different systems, with checks and paperwork at most borders, and delays for locomotive changes and awaiting train paths between each system's passenger trains. Also, the train's length and weight will be constrained to the lowest values *en route*, and it will be run on contracts made by one railway on behalf of others, all with local commercial priorities.

EU transport policy

Recent EU policy has aimed to stimulate stronger competitive responses from national railway organisations, and create a 'new railway environment'. The policy promotes efficient investment and commercial freedom to innovate by separating railway infrastructure from operations and giving track access rights to new operators. The key EC Directive 91/440[1] provides for improved railway finances, accounting separation of infrastructure management and rail operations, and the first step in track access rights. However, Europe's railways remain organised on national lines, and policies to protect national rail interests remain in place. The EU, through a Rail Policy 'White Paper'[2] and further Directives, aims to strengthen competition and promote rail freight.

The TERFFs concept

TERFFs are a key initiative in this policy evolution. The initial TERFFs are the Belgium-France-Italy / Spain, 'Belifret' Corridor, set up in 1997; North-South Freeways, with six corridors (Scandinavia/Germany-Italy /Austria); and the Glasgow-Sopron (Hungary) TERFF. None of these has been used as intended and by the end of 1999 no trains at all had used the Glasgow-Sopron TERFF.

The TERFFs idea is intended to address the problems faced by international rail freight users by providing attractive and readily available, seamless international train paths which can be 'purchased' at short notice by a train operator or other rail customer. It is not an infrastructure concept, reflecting the fact that many problems facing international freight in Europe are institutional in nature. The basic features of the TERFF concept are as follows:

- voluntary agreement between infrastructure managers (IMs) along existing international railway routes to operate a freeway
- a set of attractive train paths available to purchase at short notice from a 'one-stop shop' (OSS)
- IMs' agreement to pass control of TERFF train paths to the OSS to allow them to be marketed at a single throughout price, under the terms of a single contract
- management by the OSS (eg monitoring of trains and dealing with delays)
- customers who are licensed railway undertakings (LRUs), who provide international rail freight operations
- payment by TERFF customers to the OSS for use of TERFF train paths and OSS payment to the IMs.

Rail freight in the CEECs

The first phase of the Arup study involved extensive research into the institutional, economic, and technical conditions faced by those handling freight on CEEC railways, to identify specific problems which extensions of the TERFFs idea might help to address. Railways in the CEECs played a vital strategic role in the industrial systems of the former command economies, shifting huge quantities of bulk commodities. They are now exposed to similar types of competitive pressure as Western European railways.

1. Electrically hauled mixed freight on a Polish main line.

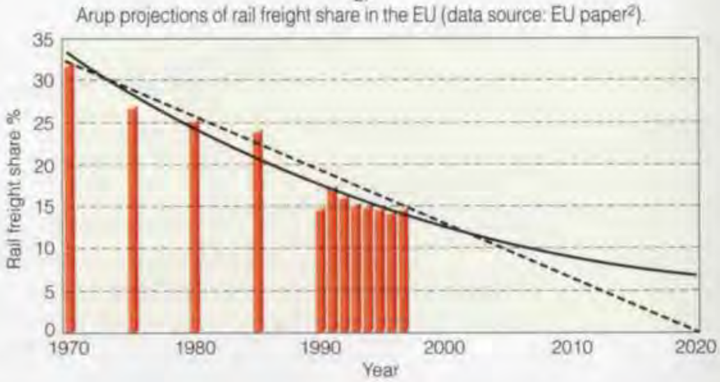
During the 1990s, the CEECs experienced major changes in the composition of their industrial output and in the structure and pattern of their trade. Fig 3 shows the main international rail freight flows in Central Europe in 1996 - the dominance of flows between neighbouring countries is clear.

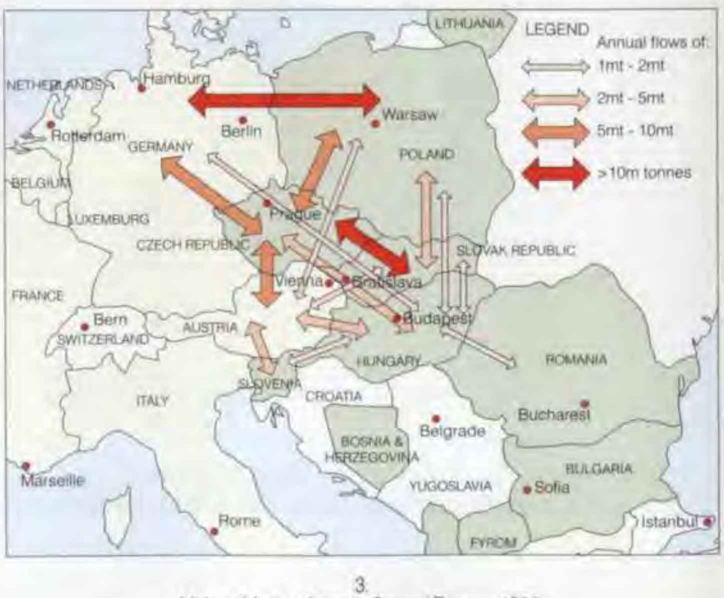
Financial constraints and organisational inertia make the railways' response to changes in their competitive environments sluggish and inflexible. However, the relatively poor road networks and relatively dense rail networks offer opportunities to arrest the decline of rail freight share at an early stage.

Assimilating the CEECs into the EU trading system will increase the average distance goods travel in Europe, and offers great opportunities for developing international long-distance freight.

CEEC railways have strong technical compatibility through the general use of UIC *(Union Internationale des Chemins de Fer)* standards, standard track gauge for the main network, and axle loads on main routes of 20 or 22 tonnes. Freight wagon fleets were a major concern for the study team. There are insufficient wagons of designs appropriate to new / growing markets, and wagon condition is generally poor, leading to problems of acceptance by EU railways, and difficulties for shippers.

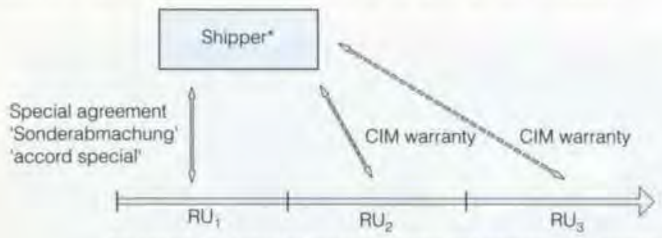
2. Arup projections of rail freight share in the EU (data source: EU paper[2]).





3. Main rail freight flows in Central Europe, 1996.

4.
Organisation of international rail freight: classical co-operation between customer and rail transport operator in CEECs.



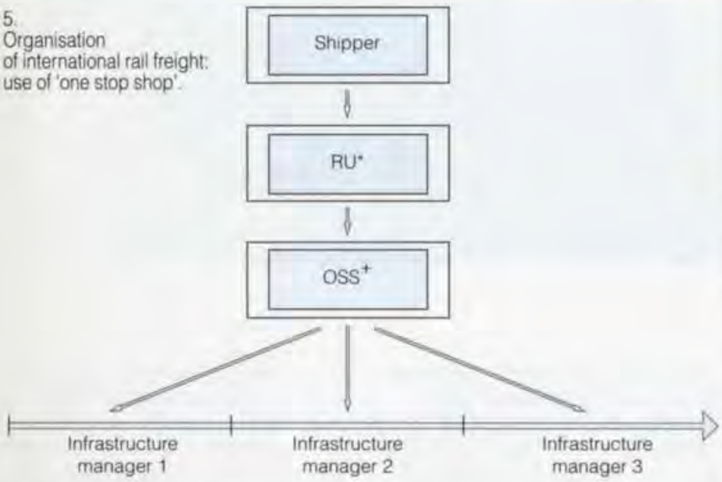
No separation between railway operator and infrastructure manager
International tariffs applied as a basis for revenue allocation

* Shipper or freight forwarder

Advantages:
Simple and familiar

Disadvantages:
No competition between Rail Undertakings RU so customers lack choice.
Lack of incentives to improve performance

5.
Organisation of international rail freight: use of 'one stop shop'.



* May be any RU with licensed access rights
+ On 'Belifret' the National railways control the OSS

Advantages:
OSS Customer care
Choice of RU for customer, providing associated benefits of competition between RUs

Disadvantages:
Possible resistance of incumbent RUs.
Infrastructure managers (IMs) are national 'monopolists'

The OSS is independent of RUs in the TERFF Model, in line with EC policy.

6.
Potential TERFFs corridors in CEECs: general proposals.

Track access and charging regimes have been liberalised in many CEECs. There is, at least in principle, open access to the national rail network by (domestic) LRUs in the Czech Republic, Slovakia, Romania, Poland, and Hungary, but common problems face incumbent national railway freight operators who set freight tariffs to cross-subsidise their regulated passenger operations. This leaves them vulnerable to 'cherry picking' profitable business. The Czech Republic and Poland were noted for already having several domestic open access operators. This appears to have provoked competitive responses. Romania has undertaken some of the most radical restructuring to modernise its rail industry.

Organisation of international rail freight

Another important aspect of the team's work was to identify an appropriate version of the TERFF concept which took account of the specific conditions in the CEECs. Fig 4 illustrates the traditional CEEC contractual arrangements for international freight, whilst Fig 5 shows the TERFF concept.

Generation of possible TERFF corridors in CEECs

The second and third phases of the project involved identifying possible TERFF schemes, and developing advice for possible implementation of pilot schemes. Four corridors (Fig 6) were identified on the basis of volumes of trade, institutional conditions, and specific railway 'supply side' conditions:

(A) Germany / Czech Republic / Slovak Republic / Hungary
(B) Polish ports / Hungary
(C) Italy / Slovenia / Hungary
(D) Hungary / Romania (with possible extension to Bulgaria / Turkey).

Work was undertaken to identify specific routes suitable for TERFF operation.

Consultation and feedback

Consultation with industry was a very important aspect of the team's work.

Over 40 interviews were carried out with CEEC organisations, and a two-day conference for about 50 delegates from railways and governments was held in Budapest in September 1999, where there was considerable interest and discussion about possibilities for implementing TERFF schemes in the CEECs. Delegates were given the results of the team's work and discussed specific opportunities; there was broad agreement that the corridors selected were appropriate. It was concluded that the concept will be useful within the next three to five years but that other problems will need to be solved before TERFF implementation.

Project outcomes

In addition to the TERFF extension network proposals, the study team responded to the feedback from the Budapest conference, and focussed on problems highlighted at the conference, including:

- how to finance and procure an appropriate wagon fleet for CEEC needs
- addressing border crossing delays
- improving co-ordination of international timetabling
- developing a Pan-European tracking and tracing system with customer focus, which would also improve rolling stock productivity.

A small conference for international timetable planners was then held in Prague. Delegates felt this was very useful for improving communication and co-ordination of international freight. This is significant since there is an established mechanism for international railway schedule planning which involves a series of stages over many months but cannot focus clearly on specific routes. Further meetings of the group were planned, and 'Round Table' meetings of senior railway managers were recommended to raise the priority of international freight in operations planning.

The fundamental difficulty experienced in Western Europe - and the source of most of the above problems - is that, as long as railways remain unreformed without strict separation of infrastructure and operations and retain national monopolies of rail freight, they have every incentive to safeguard existing rail freight revenue and to try to attract new rail freight under the traditional contractual regimes. This is proving a 'tough nut' to crack, but the recent Trans European Rail Freight Network (TERFN) agreement is the next step in freeing up access to the rail network and improving the quality of rail freight.

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Credits

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European Commission/Phare Programme

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Arup Ian Birch, Nicolette Gaillard, Ed Humphreys, Geoff Styles, Richard Thurlow, Alan Turner

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Globalisation without economic colonisation

Duncan Michael

This article formed part of a paper presented to an international conference with the theme 'strategies for globalisation'.

1.

I dislike long words, and so react badly to management magazine language. Neither 'strategy' nor 'globalisation' is a beautiful word to me. Nonetheless the meaning is quite clear, namely, what we are going to do for the future: no more than that, and no less. It is the key business question.

As to 'globalisation without economic colonisation', 'colonisation' is as long a word as that theme pair. Also it is much more ugly a word, but at least it is not hollow management speech. My views are based on long, large, and real experience of working in many countries, with many cultures and customs, with many languages, with many religions, with varied wealth, and with all sorts of politics. And always it has involved working with people - almost always enjoyably, and with a fair degree of acceptability and success.

I will use the words theme 'strategy', 'globalisation', and 'colonisation' very seldom in this article. Nonetheless, it will look at some big issues which, in my view, neither the technologists, nor the planners, nor the governments, nor the nations, nor indeed the United Nations, have real control over. However, these issues matter, and by our actions we can make progress with them easier or harder, better or worse.

The future external context

First there is the 'e-revolution' - except that it is not just a revolution but rather an open highway, defining and laying itself as it rolls ahead. It is the flavour for the next 10, 20, or 40 years.
It offers changes - at least incremental, maybe exponential - in being cheaper, smarter, more reliable, and faster (and easier for the young compared with some other topics like mathematics). It offers these changes in such abundance that through it we are creating a new world - and not a fixed one but a dynamic one. That is why I think that 'revolution' is not a full enough word to describe it. However, I do not see the advantages of face-to-face, touching hands, and eating together in any way lessened by the e-world. We will just all do more, much more. I hope that it will also be much better.

Next, investors are becoming less attached to location. They will place their money where they can get the best reward, with least risk. Of course they will assess the risks wrongly often and make mistakes. We only have to look at the capital rushing round the world at present; there are unimaginable volumes of free capital, and there are big mistakes. But the mobile investors, the communicators, the open-minded leaders, are the group which includes today's successful people.

The alternative of sitting tight and hoping that change will not happen to oneself is a losers' plan. The mobile learn from their mistakes, or rather their experiences, and steadily get better and more successful. An amazing 30% of all international trade is now done by only 50 companies worldwide, and the trend continues.

At a more procedural level, the World Trade Organisation will over time continue the progress made by its predecessor, GATT (the General Agreement on Tariffs and Trade, signed surprisingly far back in 1947), and accumulate ways to make international trade in goods, in services, in knowledge, in jobs, easier and therefore greater in volume.

The fact that the WTO got it wrong in Seattle and Davos is irrelevant in the medium term. The WTO will redefine itself and resume, and be all the more effective. It is in this context that we will all have to work. The emergence of freely trading groups of nations and also of a single currency for most of Europe show the direction and power of these forces.

Language is a multi-aspect issue. For efficiency, a single, common, accepted (and I think rule-based) language is self-evidently good for the world, good for trade, good for safety, good for learning, and good for peace. But our languages are the vehicles for so much of our cultures and our identities that we are very attached to them.

That communications should have developed so rapidly just when the British were the dominant trade and naval country of the world (and were then followed by another English-speaking country) has meant that, *de facto*, English is the *lingua franca*. It is not a very rule-based language but its mongrel sourcing, its multiple equivalent words, and its free forms make it a very dynamic language, reinventing itself continually.
The resulting endemic ambiguity can often be as much a great help as a hindrance.

At a much more trivial level, international travel is cheap, safe, and far too easy. It will continue so, it seems to me, for a long time.

These are five of the big forces which will shape the context of our lives and our businesses for many years ahead. It gives the context in which we will work. We can make them all easier or harder by our reactions but we cannot alter the total picture.

Some current tendencies

Beyond these, there are some other important but less basic issues which influence our attitudes and actions at present.

First, there is the question of size. For a long time 'bigger was better', indeed for most of history. 'Great' and 'grand' are positive words, 'little' carries insult very easily. To be fat was to be healthy. Then everyone began saying 'small is beautiful' through the 1960s and 1970s, though of course beauty is in the eye of the beholder. Nevertheless it was a most useful loosening of attitudes and went well with fear of nuclear war and fear of running out of oil, copper, food, and water.

Now, however, advertisers can again use 'size matters', with all its undertones, as a strong message, and big is OK. We see airlines joining up, except that regulators block them, and so they form alliances. We see banks and other financial bodies cannibalising each other in takeovers, with other banks taking turns at being the cooks.

The e-world and the media world are doing it in every way imaginable - alliancing, buying, strategic holding, trading agreements, networking, and so on. Management consultants, accountants, lawyers - all their biggest firms have been getting much bigger. That may be reaching a slowdown now. In technology, and especially in consultancy - in other words technological advice - the rush to be super-big has not happened so much. Arguably the financial prizes are not so big: in short, greed has less scope to play its part, instead pure efficiency is the driver.

It is odd that, in this day and age, technology - which enables just about everything new that we desire - has so little financial cunning when it comes to offering itself. But it does not matter either. We in the business of technological consultancy are all relatively hugely fulfilled, as people in many other activities are not.

It is easy to envisage firms of 20 000 people in technical consultancy - and I exclude groups of technologists like the people in IBM or in Chinese State Railways who have a captive consultancy market in the form of their own employer.

I can see 20 000-person technology advice firms prospering in the open free market.

What produces this? Well, ambition to start. Someone somewhere is trying to do it all the time. At present it seems that the extra costs of the bureaucracy, the energies diverted to uniting a firm, are still less than the competitive advantages of large technical richness. I used to reject the polarisation picture of the supply market being made up of a few big firms, lots of little firms, and no middle-sized firms. But it does seem repeatedly as if this is the case. The complete model can be made if you see it as dynamic, always changing in detail, but with the total picture much more constant in shape. Particular firms continually enter the middle zone, but are unable to rest and so shoot on to become big, or collapse to being small, or break up, or get absorbed into a big firm.

Next there is the matter of promoting technical consultancy organisations within a developing part of the world, like the Asia Pacific region. I do think that the concept would benefit from focused consideration and clearer definition. Should lots of organisations be allowed to operate freely in the region? Or do they need to be controlled by forces overtly based within the region? Or do they need to be owned by citizens within the region (or, as a variation, majority-owned)? You get very different answers depending on your choice amongst those three models. There are cases for and against each.

Again, there is the matter of establishing, developing, and upgrading technical consulting capabilities within the region. These issues are linked to the nature of the organisations as I have just discussed. How does one upgrade technology? A firm can train its own people; it can go out and hire a slightly older generation to bring in skills; it can acquire whole teams or other firms. These approaches all have different outcomes for the immediate upgrade and for the future beyond. However, updating and upgrading only allow you, at best, to keep up with the competition - the inherent weakness of benchmarking as a method.

A firm has to update in any case just to stand still, because the market and its competitors are not static but are improving themselves all the time. It can be seen as a persistent pattern on a moving platform.

There is also the creation of new skills, new businesses, even new markets. If you could design a bridge to span a clear 5km safely and at little extra cost per metre, customers would be queuing up. But they aren't. Why not, since there are many locations where one would be desirable and promoters or governments would see it as an asset beyond mere convenience? Because they don't bother to seek, to want what they don't believe they can get. So good new product creates new markets, premium markets, and is much better than upgrading, if you can do it. Let us look at 'colonisation' for a moment. It is the same coin as imperialism, just the other side of the coin. It carries a lot of baggage, a lot of history, and history that is too recent to be examined dispassionately.

But I say this. To focus on the issues around colonisation, to fight it off, is to be rerunning one's last war and the issues and tactics that went with it. This is an inherently flawed approach. It is like driving along the road and relying largely on the rear view mirror. I say look forward and discount the past. There are in many mythologies stories of the dreadful fate of the person who looked back, turning into salt or stone. That was the old way of saying 'keep looking forward'. Recollection and reminiscing are for the grandparents, not the leaders. Then what are possible business approaches? In nature there are two great strategies, 'fight' or 'flight'.

Humans are party to this and most of our decision-making is about which to do. The tactics of fight and the tactics of flight are so very different that you cannot mix them.

But today we have a third strategic choice, namely 'join'. It is a superior strategy as it depends totally on brain and very little on muscle - other than voice muscles.

I see no withdrawal strategy that can deliver success. To take any variable like the law, the technology, the organisations, the qualifications, the licences, and say 'protect it by no change!' is worthless, always, in the long term. Even great China learned that to its serious embarrassment through the last few hundred years, and is only now out of the strategic error. To build barriers and walls is to lose more than a nation gains even in the short term. And in today's technological frenzy even the long term is quite short. So I repeat: the only way is forward, looking forward, thinking forward, acting forward, and taking only the baggage that you need in a 'join' strategy and not a 'fight' or 'flight' strategy.

Conclusions

To me the shape of the future for technical consultants is very clear - not in detail, but in concept, in vision. The important issues will be quality of skill, capacity to deliver, reliability, and speed. Source, like nationality, will be unimportant (except where someone arbitrarily makes it so). Price will not be the issue. Single supply for large bundles of different items will be attractive to investors but that has to be coupled with quality; in another word, specialists. Clients will want the best, because global information is so pervasive that they have become remarkably aware of what they can have.

The role of the general practitioner will be limited, as he can always be beaten by a different specialist on whatever issue he gets challenged.

Oddly, I said all this, almost exactly, once before, in an in-house paper in 1987 for an Arup world conference. I called it 'If We Were All One'. It had the same data, the same analysis, and the same forecasts. It was not greatly welcomed, as it can be read as a threat, as imperialism and colonisation. But it was not and it is not. All will benefit, all will have a vote, all will move along with the pace, in an inclusive future. I feel encouraged to persist in my views.

This article is based on a talk given to the Conference on Strategies for Globalisation, Kuala Lumpur, 12 April 2000, sponsored by the United Nations agency the Economic and Social Commission for Asia and the Pacific, through its Technical Consultancy Development Programme.

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2.
Engineering can link nations: the Øresund Bridge between Denmark and Sweden (see overleaf) under construction.

PHOTO: JORGEN NISSEN

The Øresund Bridge:
View west towards Denmark.

The Øresund Bridge:
View east towards Sweden.

ARUP

1.

Introduction

The Øresund Bridge opened on 1 July 2000. Queen Margrethe II of Denmark and King Carl Gustav XVI of Sweden travelled by train from their respective countries to its centre, together with their Prime Ministers and other dignitaries. Here the trains were linked before bringing the party to the opening ceremony at Lernacken on the Swedish side.

For the first time ever, Sweden is joined permanently to the mainland of Europe. Up to now the link has been known as just that - the 'Øresund Link': 8km of bridge and 4km of immersed tunnel, joined by a 4km long artificial island - but its recent renaming as the Øresund Bridge reflects the visual impact of what now stands in the waters between Sweden and Denmark. And its cultural and economic effects are even more far-reaching. It reduces the journey time between the two countries to a 10-minute drive or train journey, in effect joining the capital city of Denmark, Copenhagen, with Sweden's third city, Malmö. The resulting region has 3.2M people, a Gross National Product which places it eighth in Europe, and the sixth largest European air traffic hub. The Øresund Region is set to become a strong growth area, capable of attracting investment and competing with other major European regional centres.

The opening marked the end of eight years of planning and implementation by the Owner of the link, Øresundskonsortiet (now Øresundsbro Konsortiet), a 50:50 joint venture between the two governments that has been responsible for financing, planning, designing, and building the link, and is now operating it. Øresundskonsortiet set up a special process for implementing the project that relied to a large extent on co-operation, trust, openness, and transparency, and which was a major contributor to the success of the project.

Arup's involvement goes back to December 1992, when the firm responded to a call for prequalification of consultants to take part in a competition for the bridge's design. Arup then formed the ASO Group with SETEC (France), Gimsing & Madsen and ISC (both Denmark), Tyréns (Sweden), and with Georg Rotne (Denmark) as architect to the Group. ASO was invited to take part in the competition in January 1993, together with five other international groups.

The design competition took place over two months early in 1993 and the result was announced in July that year. Two distinctly different bridge concepts were chosen by the Owner for further development before making a final choice: ASO's two-level, mainly steel, structure, with the motorway placed above the railway; and a single-level, mainly concrete, bridge, with the motorway between the two railway tracks, developed by the ØLC consortium. Both had a cable-stayed main span.

Following the awards, scheme designs were prepared to confirm the concepts developed during the short competition period, and the consultants worked with the Owner to develop the project and prepare for the construction phase. Activities included consultations with authorities to obtain their approval, establishing a design basis and a contract strategy, setting up administrative procedures, developing the design in some detail, and preparing tender documents. ASO's strong and robust design concept was safely carried through this whole design process with only very few and minor modifications.

(A fuller description of the background to the project and the design of the bridge was given in *The Arup Journal* 50th Anniversary Issue[1].)

The Owner had early decided to let the contracts as design-and-construct contracts, but modified so as to safeguard the conceptual designs that had been prepared. In essence the contracts were for detailed design and construction. Tender documents were issued for both proposals in December 1994, for two contracts for each: one for the approach spans, and the other for the cable-stayed spans. The tenders were returned in June 1995, and following evaluation of them, a single contract was signed with Sundlink Contractors in November 1995 for the whole of ASO Group's two-level design for the bridge.

The other two main contracts - one for Dredging and Reclamation and one for the Tunnel - had been let during the summer, and several coast-to-coast contracts were let during 1997-98 for the railway and for various installations such as SCADA / traffic control, communications, toll system and the terminal area.

Contract documents

The principles behind the Owner's contract strategy were:

- detailed design-and-build
- a 100 years' service life
- application of well-known technology
- control and documentation of quality
- division of risks attributable to ground and weather conditions and obtaining permits.

The contract documents were written expressly for the project, and defined the Owner's requirements regarding function, aesthetics, safety, and environmental protection. Everything required to fulfil those requirements was included in the Contractor's scope of work, with only specified duties on the Owner. The Contractor was responsible for the detailed design as well as for the construction of the work, and was given considerable freedom regarding the means and methods of doing his work. In essence the Owner specified what the Contractor should achieve, and the Contractor determined how to achieve it. The Contractor was responsible for supervising his own work and for providing documentary evidence that he had done so and that the quality of the work he had done was of the standard required by the Contract. The Owner monitored the Contractor's performance but this did not relieve the Contractor of his obligations under the contract. This contract strategy led to several special documents being included in the tender documents issued to the bidders, in particular definition drawings, an illustrative design, reference conditions, and quality system requirements.

The definition drawings described the design features, geometry, and materials that should be retained in the Contractor's design, and at the same time defined the limits within which he had the freedom to choose. The illustrative design showed the bidders, for information only, a comprehensive design that fulfilled the Owner's requirements.

Klaus Falbe-Hansen

The Øresund Bridge completion

Jørgen Nissen

The reference conditions defined benchmark values for ground and weather conditions, outside which the Contractor was entitled to compensation, whilst the quality system requirements described the Owner's requirements to the Contractor's quality system. The Contractor was required to establish, maintain and adhere to a project quality programme, specifically adapted to the Contract. A quality manual - including general procedures - and several quality plans were to support the project quality programme.

WINNER
British Construction Industry 2000 Award for an International Project

The quality manual and the general procedures set out the overall systems and principles governing all activities under the Contract.

The quality plans, with method statements and work procedures, would be the contractor's operative instruments for planning, executing, and controlling the numerous work activities.

Under the Contract, the Contractor had full responsibility for quality control of the works. The Owner monitored the Contractor's adherence to his quality plans and procedures. ASO Group was responsible for technical monitoring and audits of the Contractor's detailed design and construction work, working closely with the Owner's staff. To do so, ASO approved the basic design, reviewed working drawings, approved the quality system documentation, reviewed construction method statements, monitored construction activities, and participated in and carried out audits.

4.
Caissons were cast at the Malmö yard.

2.
The fabrication yard at Malmö North Harbour.

3.
Pier shafts were cast at the Malmö yard.

5.
Caissons for the pylons were cast in Malmö in dry dock.

6.
Completed caissons ready for transport to site.

The main part of this article concerns the design of the bridge and Arup's involvement in that process. However, a series of issues needed to be dealt with for the tunnel and bridge in combination. Øresundskonsortiet asked Arup to help, through the firm's specialist groups shown in the panels below and overleaf.

Risk studies

Charles Milloy

In addition to Arup's work on the bridge, the firm was involved with developing the Operational Risk Assessment of the entire Øresund link. The Owner commissioned Øresund Link Consultants to carry out the risk assessment but felt that the process would benefit from the contribution of external reviewers, so Professor Tendrup Pedersen from the Danish Technical University was appointed to review the marine aspects and Arup to review the remainder. To our knowledge, it is the first time such a comprehensive risk analysis has been undertaken during the design of a major fixed link.

A fully quantified risk assessment of the human safety and traffic delay risks was carried out for a comprehensive list of hazards:

- fire • explosion • train collisions and derailments
- road accidents • ship collisions and groundings
- aircraft collisions • toxic spillages
- environmental loads beyond design basis.

Initially, the assessment attempted solely to identity the risks beyond those of typical stretches of motorway and railway on mainland Denmark or Sweden. However, it soon became clear that this approach could be improved by considering total risks and being able to compare the Link's risks with international risk acceptance criteria. The risk assessment was carried out concurrent with the design process and influenced several design decisions, the most significant being the size of the bridge pier foundations to withstand ship impact, the realignment of the main shipping channel to reduce groundings, and the provision of passive fire protection on the tunnel walls and ceilings.

7.
The fabrication yard at Cádiz.

8.
Two completed girders are ready for being transferred to ocean-going barge.

9.
Approach girders on barge en route for Malmö.

10 below:
The lower deck in the approach girders was completed in the Malmö yard.

11.
Main span girders were fabricated in Karlskrona.

Corrosion protection

Graham Gedge

The design team and client rightly recognised, early in the design process, that corrosion protection of the bridges' steel girders was a potentially significant issue, and during the original design Arup Research & Development was commissioned by the client to develop a corrosion protection specification for all the externally exposed steel.

The brief required Arup to:

- consider specifications based on both conventional and emerging coating technology
- optimise the life to maintenance of the specification
- consider specifications that minimised both health and safety risks and environmental impact.

Specifications considered included glass flake epoxies, solvent-free polyurethane, and conventional epoxies using a zinc-rich primer.

The chosen specification is shown in Table 1.

At first sight this is a conventional specification, but it has been optimised to provide the maximum possible thickness of barrier coats over a primer that is sensitive to the thickness of top coats.

The specification was applied to surfaces blast-cleaned to Sa 2 1/2 of ISO 8501-1 and all coats were shop-applied.

Table 1 Coating specification

Coating	*Material*	*Thickness (m)*
Primer	Zinc rich epoxy	40
Barrier 1	Epoxy micaceous iron oxide	150
Barrier 2	Epoxy micaceous iron oxide	150
Finish	Polyurethane	50

During the detailed design Arup reviewed the contractor's steelwork design and made recommendations for changes to eliminate water retention on the structure:

- by ensuring free run off at node points.
- by highlighting fabrication details that could act as water traps.

Also during this phase Arup undertook a detailed review of the contractor's quality assurance and quality control procedures to ensure that these were adequate to provide confidence in the quality of the finished product.

During fabrication and erection Arup had a continued role:

- advising on remedial works specification
- helping the contractor resolve the technical problems that inevitably arise on such a large project
- monitoring the contractor's testing procedures and records as work progressed
- advising the client on the possible consequences of changes to both the specification and / or the quality plan.

During fabrication and erection, AR&D representatives regularly visited both the bridge site and the fabrication yards in Sweden and Spain, and Arup involvement continued up to completion of the bridges with detailed visual inspections of the steel.These were needed to identify areas requiring remedial works and advise on how to deal on site with issues such as over-spray that were detrimental to the appearance of the structure and could also have an impact on the long-term durability of the corrosion protection.

Construction of the bridge

A fundamental principle adopted in developing the conceptual design was that it should allow for economical construction, resulting in the minimum possible adverse environmental impact.

The objectives the design team set themselves were to demonstrate that the design was practical, that it could be built within the implementation programme set by the Owner, and that it would allow competitive tendering for the proposed design- and-construct contracts. This was achieved by incorporating scope for factory-type prefabrication of large sections of each element, for large-scale erection operations for which tenderers would be able to utilise existing plant, and for repetition of detail design and construction details.

The selected Contractor to a high degree based his tender on these assumptions, and the major part of the bridge was fabricated on-shore. Production of caissons to support the piers for the 49 approach spans started in late 1996 at the fabrication yard in Malmö North Harbour, from where the heavy lift vessel 'Svanen' collected the caissons and the pier shafts for transportation and placing in the bridge line. At load-out these caissons weighed between 2500 and 4700 tonnes. The pier shafts varied from 13m to 51m in height and from 900 to 3300 tonnes in load-out weight. The 19 000 tonne caissons for the two pylons were too heavy for 'Svanen', which has a maximum lifting capacity of 9500 tonnes, so they were constructed in a nearby dry dock in Malmö Central Harbour. A purpose-built catamaran was used to lift, transport and place them.

Seabed levels at pier positions vary from -3m to -9m and foundation levels from -8.5m to -18m. All pier and pylon caissons were placed on three pre-positioned concrete pads. The narrow space remaining between the limestone seabed and the underside of the caisson was grouted and the caissons ballasted. Backfilling up to seabed level and scour protection completed the foundation.

The pylons were the only major element of the bridge to be constructed in situ. A traditional climbing form, each lift being 4m, was used. The 140m long approach span deck girders were prefabricated in Cádiz in southern Spain. Fully painted, these girders were transported in pairs on ocean-going barges from Cádiz to the yard in Malmö North Harbour where the prefabricated lower railway troughs were installed. Erection in the bridge line was once again by 'Svanen'.

At final load-out the deck elements weighed between 5500 and 6900 tonnes, close to the lifting capacity of 'Svanen', considering its purpose-built 1800 tonnes lifting gear. The cable-stayed deck girder, however, was produced in Karlskrona, Sweden, some 200km from the site. Steel sections 140m long were transported on barges to Malmö North Harbour where the upper roadway deck was cast before the girders were installed by 'Svanen'.

The shallowness of the Øresund waters, combined with the fact that the Flintrännan navigation channel is being realigned as part of the implementation of the link, gave a special advantage for erecting the cable-stayed bridge. The 490m main span was erected in four sections, which were able to be supported by temporary towers founded on the seabed at level -8 to -10m. After completion of the main span the shipping traffic was moved to its new position.

12 above, and 13 below: The main pylons were cast in situ.

14.
Svanen lifting caisson at the Malmö yard.

15 below:
Svanen placing pier shaft.

16 below:
Approach girder being transported to bridge line by Svanen.

17 right:
Svanen placing approach girder.

18.
Completing the railway deck in approach bridge.

19.
The last girder is placed.

More overleaf ▶

20.
The main span was erected in four sections supported by temporary towers.

23 right:
Surfacing and waterproofing was carried out under large tent.

21 above:
The main span nearing completion.

22 left:
The original navigation channel was used until main span was completed.

24 above:
Placing the main cables.

25 below:
Cable anchorage.

Conclusion

Bearing in mind the massive budget and time overruns on previous comparably-scaled infrastructure projects, the Owner quite deliberately devised a special - even unique - process for implementing the Øresund link. In practice, the modified design-and-construct contract worked well.

The Contractor was responsible for delivering a quality assured product in accordance with the Owner's requirements. By giving the Contractor the responsibility for the detailed design, the design could be refined and optimised to suit his precise preferred construction method as long as the design requirements and the definition drawings were adhered to. By including comprehensive definition drawings as part of the contract documents, the Owner ensured he would receive a project that not only fulfilled his quality requirements on materials and workmanship, but also has the appearance he envisaged before he signed the Contract.

Fire engineering

Chris Barber

It is a key factor in high investment / regional development projects that risk of failure is understood and anticipated in the design.

Understanding fire risk is an obvious part of this assessment process. For Øresund there was a good deal of sensitivity to fire issues, following the tunnel construction fire in the Storebælt link and later the Channel Tunnel fire.

Arup Fire studied and reported on the possible fire scenarios that could result from rail and road traffic accidents.

Whilst life safety checks formed part of the work, the principal objective became the understanding of continuity of operation following a fire and the need or otherwise for additional fire protection material. Initial studies were based on qualitative risk assessment using fire events referenced or derived from elsewhere.

Using parameters related to cost efficiency, maintenance, and weight (in the case of the bridge) some of the larger, more aggressive scenarios fell outside the boundaries envisaged by the designs.

Through an iterative study process with the risk engineers, the worst fires were shown to be outside credible probability limits and therefore eliminated from the design process. The refined quantified risk assessment, in combination with fire engineering, took account of variables in Link traffic and its type, together with the total sequence of events needing to occur before a severe fire could develop.

26 left:
Testing the railway.

27 below:
The Copenhagen-Malmö Express in the Bridge.

Prefabrication was used extensively, to safely give quality, speed, and efficient construction. With the modified design-and-construct approach, an integrated design process could be used. Production and work could be organised with the aim of simplicity and efficiency, as the detailed design could be developed concurrently with the construction methods.

The Øresund Bridge is now complete. The Owner's strategy of co-operation, trust, and openness has been a success. The Contract was on time and on budget. The quality of the permanent works is to the Owner's satisfaction.

There were no disputes and no significant claims against the Owner. This is not usual for a project of this size and complexity and can to a large degree be attributed to the spirit of partnership which developed in this truly international project linking Denmark and Sweden. The tunnel is the longest immersed concrete tunnel in the world. With its main span of 490m, the bridge ranks as joint ninth among cable-stayed bridges around the world. However, it includes the longest free span of any cable-stayed bridge carrying both road and rail traffic, it is the longest double-deck bridge for road and rail traffic, and it has by far the highest freestanding pylons in the world.

Reference

(1) NISSEN, J. The Øresund Link. *The Arup Journal*, *31*(2), pp37-41, 2/1996. [This article included a statistical summary and credits list for the project.]

Credits

Illustrations:
1, 9, 13, 27, 28: Jørgen Nissen
10, 20, 22, 25: Klaus Falbe-Hansen
2 to 8, 11, 15 to 19, 23, 24, 26: Pierre Mens
12: Øresundsbro Konsortiet

28.
The cable anchorages extend beyond the bridge deck.

Camden Neighbourhood Regeneration

Jerome Frost

Introduction

Arup's headquarters has been in the 'Fitzrovia' area of central London since Ove Arup founded the firm in 1946. More recently its presence has extended north to Camden Town and to various closer locations in the London Borough of Camden. Arup is now one of Camden's largest employers and widely acknowledged as an active supporter of the Borough's civic life. The firm also helps sustain the livelihood of many other local businesses, from graphic design studios to cycle couriers and sandwich shops. Over the past 40 years Arup has been involved in a variety of major projects in Camden, including the British Library, and Euston and Regent's Plazas. It has a central role in redeveloping St Pancras and Kings Cross, and has advised on a wide variety of environmental and traffic schemes.

Strategic approach to regeneration

Arup's latest project in Camden is, however, very different. Arup Economics & Planning has just finished preparing a comprehensive Regeneration Strategy for the Borough, aimed at tackling a wide variety of social problems, from crime and homelessness to new educational opportunities, housing renewal, and health care.

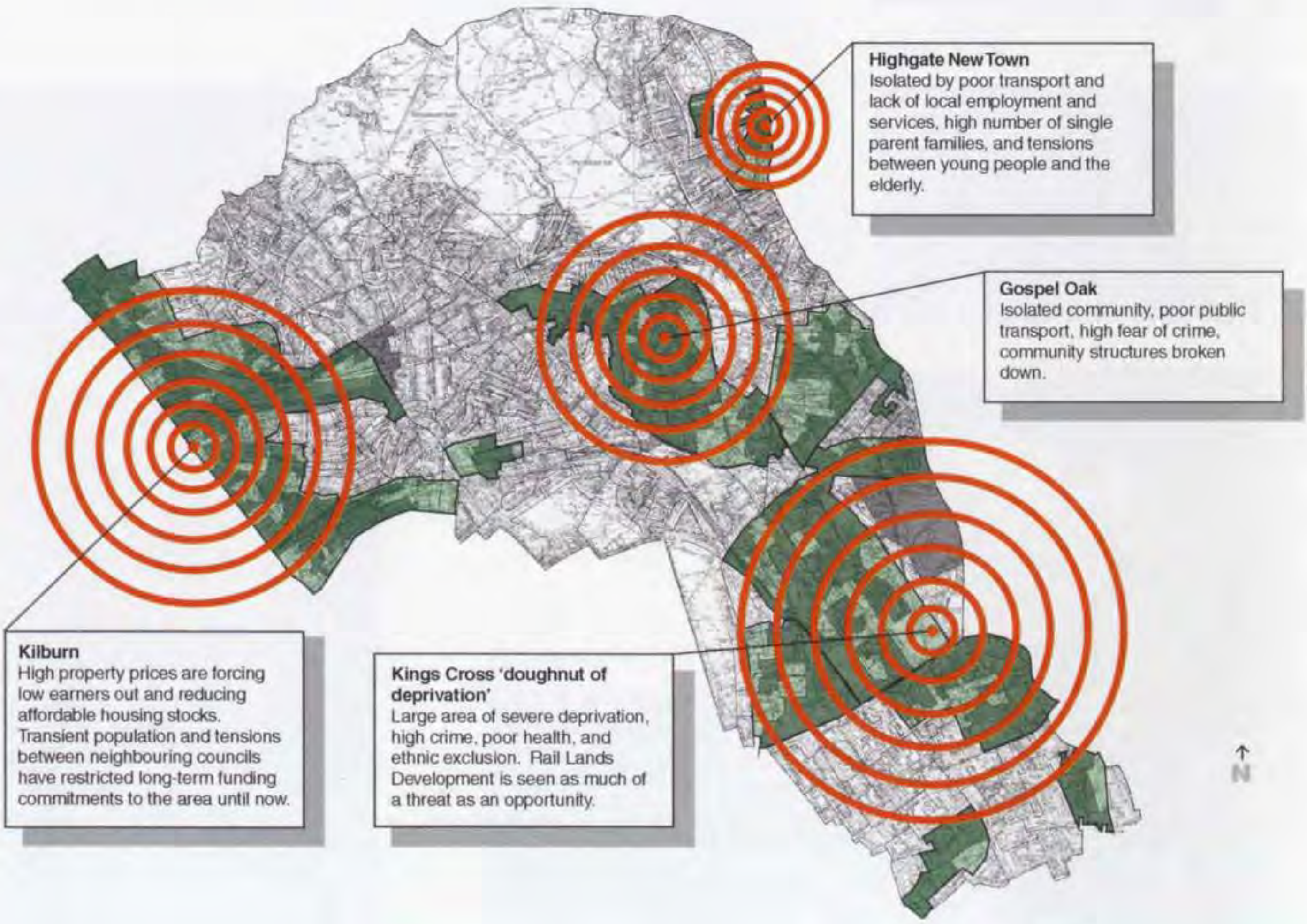
AEP's innovative approach combined statistical analysis of social and economic deprivation indicators with extensive consultation (around 300 people directly and through contact with over 500 local organisations). This provided a unique insight into perceived and 'real' issues for people living and working in some of the most deprived areas of London. Consultees included councillors, residents, local businesses, community groups, caretakers, shopkeepers, housing managers, police, youth workers, head teachers, and health workers.

Also, the study brought together all council departments, local development partnerships, housing associations, and the National Health Service, inviting them to look closer at, and the delivery of, services to the Camden community and improve their linkages with other service providers.

The results are already being seen in a much more concerted approach to tackling all aspects of deprivation, particularly health, employment, education, crime, housing, and transport. Arup has also identified the physical and social barriers that exist between different communities and analysed how people actually use the areas where they live and work. 10 neighbourhoods of priority need were identified in the Borough, and new tailor-made approaches to regeneration recommended. The need for physical renewal was high in some areas (particularly Gospel Oak), while in others a more urgent requirement was for social and economic change.

One important recommendation was to target the already large mainstream budgets for services in a more co-ordinated manner, rather than relying on special central government regeneration funds and programmes. The study identified many issues highlighted by the government's newly-established Social Exclusion Unit. It expanded on several, drawing attention to the needs of particular groups including the elderly, ethnic minorities, and refugees, and to the tensions between young people and their elders. In its recommendations for physical improvements, it drew on conclusions of the Urban Task Force Report[1] by suggesting greater integration of new housing designs with street patterns, a greater focus on the quality of public spaces, their long-term maintenance, and safety.

In addition, the recommendations of the April 2000 Housing Green Paper[2] were reflected in suggestions for greater tenure mixes and more active involvement of housing associations.



1.
Map showing the four priority 'target areas' for regeneration in the London Borough of Camden

Recommendations

Arup proposed a step change in partnership working between Camden Council, other local partner service providers, the business community, and local residents. Of the 10 focus areas, four priority 'target' areas were identified where extensive and immediate action was required:

The 'Deprivation Doughnut'

This is a ring of linked communities covering an area of c8km, with the Kings Cross / St Pancras Station transport interchanges at its centre. It extends north to Camden Town (right), west to Regents Park, east to Islington, and south to Holborn. Education, health, and crime indicators for this area showed its communities to be among the most deprived in England, yet within walking distance of some of London's most prosperous districts.

Recommendations for this Kings Cross 'deprivation doughnut' area focused on the need for Camden Council and its partners to work with the community to prepare and empower them to take advantage of the opportunities created by the rail lands developments, and reject the crime and negative images of the area. Central to achieving this were improvements in community representation, health services, education, and developing a 'job ready' labour pool.

Gospel Oak Estates

These are a linear series of Council-owned housing estates built in the 1960s / '70s, stretching from Hampstead in the north to Camden Town in the south. The communities living in these areas felt cut off from their surroundings and opportunities for work, training, and education. The fear of crime in public places also dominated discussions.

Recommendations for Gospel Oak (below) included physically remodelling the estates for greater integration with surrounding historic street patterns, and redesigning public spaces to make them safer and more attractive. Overridingly the need for greater community development was acknowledged, both to encourage participation in planning the area's future, and to create a stronger community spirit to give local people the confidence to reduce crime (through increased surveillance) and realise opportunities for local enterprise themselves.

2.

Highgate Newtown (right) and the Whittington Estate

These are a collection of Council-owned properties interspersed with high value owner-occupied homes between Highgate and Archway. Though amongst the smallest neighbourhoods identified, levels of deprivation were considered extremely high. The contrast between the quality of life of residents in Highgate Newtown and in nearby Highgate Village was quite startling.

Recommendations for Highgate Newtown and the Whittington Estate included improved access to public transport, and a combined approach with the London Borough of Islington to physical regeneration. Several specific vulnerable groups stood out, particularly from tensions between young people and the elderly, and the large number of single parents. Improved local facilities for training and child care, and greater community enterprise, were recommended to help the latter group, and - for the former - projects that supported co-operative working between young and old.

4.

Kilburn

This mix of council and private rented tenures interspersed with high value owner-occupied housing is close to the 3km Kilburn High Road district shopping centre. Issues here relate to the dramatic effect of rising house prices on affordable housing, and the need to preserve the vibrancy of Kilburn High Road (below) as a centre for local community activity.

5.

Recommendations for Kilburn included greater integration of private rented tenants into the community, and improved co-ordination of the numerous regeneration funding programmes currently targeted here.

Also, co-operation between Brent and Camden Councils was seen as vital to securing sustainable regeneration in the long term.

3.

Conclusion

Ultimately, the study has made it much easier for service providers and the community to work together to tackle deprivation issues cohesively.

Its recommendations relate to the 'Single Regeneration Budget', 'New Deal for Communities' and other central government and European resources in tackling local issues, but, most significantly, they stressed the importance of targeting existing budgets at those in greatest need.

The study's findings and recommendations will underpin a new regeneration strategy for Camden, and are already being used in individual Council departments to inform use of resources and capital programmes.

The work has also helped the Council to win £7M of Single Regeneration Budget funding for a £20M programme of change in the heart of the Kings Cross 'Doughnut'.

The 'joined-up', neighbourhood level, approach to sustainable regeneration now informs central government urban policy and is soon to be the focus of a new national quango. Recent public spending announcements promised extra funds: £10bn for urban regeneration, £2.7bn for education and training, and £1.6bn for housing over the next four years. This work and a wealth of related Arup projects will help to ensure that the firm continues to play a leading role in this 'once in a generation' opportunity to transform Britain's poorest areas.

References

(1) URBAN TASK FORCE. Lord Rogers of Riverside, Chairman. Towards an urban renaissance. Final report of the Urban Task Force. E&FN Spon, 1999.

(2) DEPARTMENT OF THE ENVIRONMENT, TRANSPORT AND THE REGIONS and DEPARTMENT OF SOCIAL SECURITY. Quality and choice: a decent home for all. The housing green paper. Stationery Office, 2000.

Credits

Client:
London Borough of Camden

Strategic advisers:
Arup
Jessica Cox, Jerome Frost, Pritej Mistry, Paul Whitehouse, Chris Tunnell

Illustrations:
1. Pritej Mistry
2-5: Jerome Frost

Lift modernisation, BT Tower, London

Roger Howkins

Background

The BT Tower, formerly the GPO (General Post Office) Tower and originally the Museum Tower (from the then local 'Museum' telephone exchange), dominates the London skyline, towering 190m above street level. The GPO's original design brief was for a centre of national and international telephone communications, using ultra high frequency (UHF) microwave transmissions in addition to television links. It was designed by the then Ministry of Public Building and Works and built between July 1961 and July 1964; the service's technological character and potential capacity made it a considerable advance on any existing international centre when completed in 1965.

The core, restaurant, and hospitality galleries are serviced by two high speed lifts in the 6m diameter reinforced concrete shaft that supports the entire structure. The central Tower shafts are 610mm thick at lower levels, reducing to 380mm in the aerial part. At the hospitality gallery the floor diameter is 19.8m. When construction was completed, the verticality from true of the completed shafts in the central axis was measured as within 32mm, and the symmetry of the cross-section relative to the same axis was within 100mm.

Prior to a terrorist attack on 31 October 1971, when a bomb exploded in a toilet on the 31st level, more than 4.6M people had visited the viewing galleries and revolving restaurant. Since this attack the Tower has been closed to the general public.

Project management

Arup Research & Development (AR&D) was appointed as lead consultant and project manager by British Telecom (BT) to carry out inspections and surveys, and make recommendations for the proposed modernisation of the lifts in the Tower. A report was issued in June 1998 with very detailed recommendations on the scope of works and achievable time scales in view of the planned Millennium celebrations. The report considered not only the lift requirements but also the commercial and programme risks or hazards.

The pre-tender stages were critical in forming the basis of the whole project and the procurement strategy evolved from several meetings between the design team. To ensure compliant bids were received from suitable tenderers, pre-, mid-, and post-tender meetings were held with all tenderers to clarify the requirements, both commercial and technical, of the project. This was instrumental in building a team environment which the successful lift contractor was fully expected to buy into.

After the exhaustive tender period, Thyssen Lifts were appointed as contractors. This was due not only to their technical and commercial submission, but also because of the team spirit displayed between themselves in the UK and Thyssen Aufzugge in Germany who were to provide the major drive components and full technical support throughout design and installation.

Designed around the Arup works stages and systematic approach to lift modernisation, the following milestone programme was laid down:

June 1998
Prepare specification and contract documents - *achieved*

July 1998
Interview possible lift contractors - *achieved*

July/August 1998
Bidding period - *achieved*

August 1998
Tender review period - *achieved*

September 1998
Award contract (Thyssen) - *achieved*

September 1998
Procurement of materials - *achieved*

February 1999
Commence modernisation - *achieved*

September 1999
Commissioning and practical commissioning - *achieved*

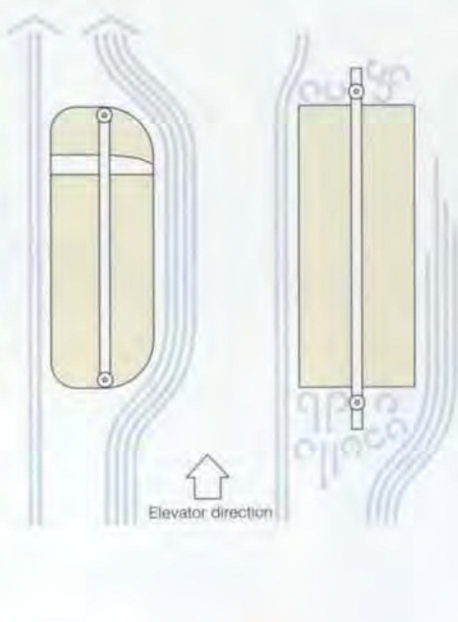
October 1999
Fully operational - *achieved.*

The brief

Tower staff, both technical and commercial, had commented on the poor, erratic and unreliable lift service, which had resulted in important corporate functions in the revolving restaurant being cancelled due to the lifts being out of service. Arup was asked initially to visually inspect them, without dismantling or carrying out any destructive testing of components, sub-assemblies, or structural elements. An added complication was that the lifts are the only viable means of emergency evacuation in a fire - the Tower is believed to be the only building in the UK where emergency evacuation is planned and designed around the lift system.

1.
Mock-up of car without the streamlined cowlings.

2 right:
The cowlings reduce internal noise levels by approximately 15db.



3.
Final as-built design concept for interior, with 'bull bar' protection for lower level glass.

4.
Original concept (as built) viewed from interior of car.

The survey

Although the 'as-constructed' structural drawings were available, original lift data were not, so the visual inspection, taking measurements and data, was made over an April weekend in 1998. This revealed defects and problem areas not fully realised by the client. The lifts were originally designed to operate at 5m/sec, in 1983 increased to 6m/sec. Arup's survey revealed that this had been drastically reduced to 3.7m/sec due to overall reliability concerns, equipment fouling from building sway, and the very poor ride quality and comfort.

On all high speed lifts ride quality is extremely important, and using the AR&D ride quality bench marking measurement system, incorporating the EVA (Elevator Vibration Analysis) Tool, the Tower lifts were defined as 'poor'. This was attributed to several factors discovered during the survey:

- loose guide fixings and connections to the reinforced concrete structure
- pinned guide rails eliminating any designed vertical movement within the rail and bracket sub-systems, causing the guides to bow and deform
- the non-aerodynamic lift car and counterweight design.

The drive units were still the original 1960s DC gearless machines, and investigations indicated that, during the last re-roping, one of the lifts had been equipped incorrectly, causing severe and highly progressive wear to the drive and secondary sheave.

The specification

Arup's database of lifts in tall buildings shows that ride comfort and passenger perception of fast lifts centres on two mechanical elements: the riding system (guide rails, brackets, and roller guides) and the aerodynamics of the car and counterweight. The survey established that the original guides were bowed and could not be re-used, and that the original cars and counterweights were not designed to for air movement at high speed. These two negative but vital elements of the original design assisted in the technical specification, as they needed to be replaced with modern, variable geometry key components, essential for fast lifts.

Also, an automatic lift speed reduction system would be required to detect high wind speeds and automatically switch in and out, dependent on the environmental conditions at the top, 190m above street level.

The structural limitations of the lift pit would only allow the maximum lift speed to be increased to 7m/sec. This limitation however, still allowed the Tower population loading to be increased by 32 people based on the evacuation time demanded by the occupation certificate.

The final technical specification required the use of energy-efficient Variable Voltage Variable Frequency (VVVF) drives. New computer control systems and sub-systems, two-hour fire rated doors, full universal access, communications and remote monitoring systems were also specified.

Theatre

The engineering scope had been well defined and tendered for and was relatively straightforward apart from the very tight programme, which was achievable providing no unforeseen problems arose.

As the Tower is BT's premier corporate event venue, the lifts had to have a certain 'wow!' factor, incorporating 'theatre' and a modern high tech image. What does 'theatre' mean in lift terms? From experience with panoramic elevators for signature architects Arup knew about materials limitations. How to design in 'wow!' and 'theatre'? With high speed lifts noise was considered an important factor - would it also be a problem?

Research on a similar high speed Thyssen installation in Europe showed that aerodynamics assisted in reducing the 'in car' noise at speeds above 4m/sec. It was agreed that to achieve the sensation of high speed in an enclosed lift car, noise was the most important factor. However, the internal pressure variants in the shaft caused by the high lift speed would produce not only natural noise, which was wanted, but also a buffeting effect, which was not. To minimise the buffeting, aerodynamic cowlings would be needed.

The next stage was the lift car environment and passenger perception of the lift. Operational requirements had given the lift cars a massive 3.8m clear internal height, which provided huge scope for work on the finishes. It was always envisaged that they would be minimalist, based on the timeless effect of glass as successfully used on many previous Arup panoramic lifts Glass has yet to realise its full potential in conventional lifts, so the initial idea was to provide cars of high quality glass and contrasting stainless steel, to achieve BT's required modern high tech feel. 'Extra White' glass was specified, a clear float glass producing high light transmission and without the green tint of ordinary clear float glass. This makes it an ideal material to edge light, especially in lift cars.

The car lighting specified was a grid of fibre optic downlighters to give a sparkling effect within the tall car and cold cathode handrail lighting to wash up and down the Extra White Glass.

Although glass would predominate, certain elements had to be stainless steel. The final pattern specified for it was an Italian-designed Linen pattern, providing a stronger contrast to the glass and easily fabricated and worked.

This provided the original concept for the lift car; what could now be done for more theatre?

Replacing the car floor and ceiling with a structural clear glass was rejected as just too frightening. Increasing the rates of acceleration and jerk were considered, but the lift experience had to be enjoyable, not frightening or uncomfortable, during normal high-speed travel.

Video monitors have been used previously in lifts but their usefulness had not been properly evaluated. It was established that the journey would provide the experience with an enhanced video voice announcement system carrying the message 'you are now travelling at 1400 feet per minute' (this having the perception of being faster than 7m/sec).

Special flat screen indicators were introduced, not only showing speed gradients but also load and the normal direction of travel and lift position indicators. For the car operating station, the final design was a special combination of conventional micro-movement push buttons illuminated with special blue LEDs and a security touch screen for access to working levels, plus a very sophisticated 'hands-free' telephone/intercom. Laser-etched tower bar indicators, with blue LED illumination, were incorporated into the car front returns.All finishes have to be cleaned and maintained, so before final selection and approval, all samples were subjected to abuse and cleaned to verify there would be no adverse affect in day-to-day use. Final approval would be given following demonstration of a mock-up car at the Thyssen Factory in Nottingham, England.

The client's cleaning contractors would also visit and provide a maintainability verdict, together with the professional team who would comment on the theatre and lift engineering of the cars.

The final verdict contained no surprises, as AR&D's systematic approach designs these issues out of the project at the correct stage so they not left as last-minute decisions.

Fire evacuation

The BT Tower is one of the very rare buildings where the lifts form a vital part of the evacuation strategy, including fire. This strategy has been well developed over many years and is based on the maximum occupation levels within the high galleries. The total number of people is based on an evacuation time of five minutes. Obviously lift speed, as is capacity when considering evacuation strategies and emergency scenarios.

Due to the increase of lift speed and increased car capacity, the population loading could be increased by 32 people without compromising safety. It was arranged that when on 'evacuation control' the lifts adopt a new speed profile providing higher rates of acceleration and jerk than normally expected, but within the limitations recommended by the whole body movement codes and standards. As the lifts are provided with new two-hour fire rated doors, new CWZ-rated electrical feeder cables, state-of-the-art communications, and very special evacuation controls, it is possible to run them safely through fire floors should the need arise.

Conclusions

With such a fast track programme it is essential that the overall objective is a completed lift, with no safety issues compromised. The Thyssen site safety book did not have a single entry, a reflection on the professionalism of their site team and the back-up provided in the UK and Germany. Also needed are a design and professional team and client who are willing to consider radical issues and make immediate decisions without referring back to other committees. The more AR&D use the systematic approach to lift modernisation, the more refined it becomes.

This project would have been extremely difficult if not impossible to complete on time and within overall budget without this approach being adopted.

5-6
Lift shaft before, and right, after refurbishment.

The final installation is very fast, has very good ride quality characteristics, incorporates the 'wow!' factor and 'theatre', and is proving extremely reliable. All sub and information systems are working as designed and the experience has been very well received by all those visiting and working within the Tower. This would not have been possible without full team co-operation and professional commitment to the project.

Credits

Client:
British Telecommunications PLC

Consulting engineer:
Arup Barry Austin, Chris Barber, John Carroll, Anthony Ferguson, Roger Howkins, David McAllister, Sarah McKenna, David Miles, John Moss, Michael Pang, Howard Porter, Peter Ross, Dave Spencer, Alex Wilson, Michele Wong

Quantity surveyor:
MDA Group

Planning supervisor:
Faithfull and Gould

Lift contractors:
Thyssen Lifts and Escalators
Thyssen Aufzugge

Building and electrical works:
Major Lift Services

Illustrations:
1, 5, 6 : Roger Howkins
2: Denis Kirtley
3, 4 : Fred English
7: John Gale, *Elevator World*

7.
Interior of mock-up, identical to operating lift.

Thames Barrier Park

Richard Bickers
Rona Burnett
Ian Carradice
David Johnston

1.
View across the sunken green dock with the new housing development 'Millennium Point' in the background.

Introduction

The vicious spiral of unemployment, poor housing and schooling, brutal townscape, and perceptions of personal security, has reduced large tracts of cities in Europe and the Americas to urban deserts. Development has been concentrated in greenfield sites, despite a plethora of initiatives and studies to reverse the trend. Successful regeneration, as at Salford Quays in the North of England, Euralille in France, parts of Barcelona, and London Docklands, are the exception rather than the rule.

The perceived financial and safety risks associated with contamination have impeded efforts to encourage investment in both financial and personal terms.

The philosophy that these derelict lands should be brought back to life and serve the needs of urban communities is rapidly gaining momentum. There is also a growing realisation that such regeneration can create sustainable urban areas, with the appropriate mixture of employment, residential, retail, education, leisure, and social infrastructure.

This article explores the role of parks in urban renewal, and how integrated design can combat perceived constraints like contamination in a realistic and economic fashion. The techniques are equally applicable to other brownfield developments.

The role of parks

High quality green space is a vital part of the urban fabric and contributes significantly to the creation of successful and prosperous urban centres. A good example is Stockley Business Park, West London[1]. Green space attracts people to live and work around it, thus encouraging the potential for mixed communities by providing views, leisure, and even a local micro-climate.

The role of engineers

One of the many important things that engineers can bring to this process is the ability to identify clearly the difference between perceived and actual risks associated with contamination and dereliction, and to provide economic and sustainable remediation solutions. These can be tailored to meet the needs of the particular redevelopment. Through being involved early, engineers can often raise the expectations of the client, investors, planner, urban designer, architect, and landscape architect. This role is illustrated by the Thames Barrier Park project.

Thames Barrier Park

Site history

The Park is in Silvertown, London Docklands, sandwiched between Royal Victoria Dock and the Thames. The site was formerly industrial, housing a chemical works, a dye works, and an armaments factory, amongst others. These industries declined - as part of the widespread decay in activity in Docklands - leaving the 9ha area derelict, its soils and groundwater contaminated. It was used to construct the Thames Flood Barrier, but since 1984 had remained vacant and derelict (Fig 2).

Regeneration concept

In 1995, the London Docklands Development Corporation (LDDC) bought the site and held an international design competition 'to create a rich and inviting public space - a park which knits into its surroundings through a clear and logical urban strategy'. The proposal was to create a publicly-funded park which would act as a catalyst for private development of the surrounding areas.

The winning design

The competition was won by a team comprising French landscape architects Groupe Signes and UK-based Patel Taylor Architects working with Arup as engineering and environmental consultants. The winning design (Fig 3) adopted simple yet bold architectural strategies which will set the scene for future architectural composition of the area.

The design concept recalls the site's dockland heritage by creating a flat, raised plateau with a deep, colourfully planted 'green dock' cut through the centre.This is orientated to provide visitors with dramatic views of the Thames Barrier as they progress from the Park entrance towards the riverside. By raising the level of the site above the level of the adjacent road, the Park is protected from intrusive noise, increasing the scope for relaxation and enjoyment.

2 below:
The site after completion of the Thames Flood Barrier.

3 below:
The architects' proposal for Thames Barrier Park with housing on three sides.

4.
'Hot spot' of contaminated material (tar) encountered during excavation.

5.
Aerial view of site after completion of the remedial works.

Features within include a pavilion building housing a cafe / restaurant, a canopy structure overflying a remembrance monument, an events area, children's playgrounds, and a water feature. These provide focal points of interest, drawing people into the Park, and generating movement and vitality.

The Park has also been designed to link into pedestrian and cycle routes, to adjacent housing areas, and to the proposed walkway along the north bank of the river Thames. It is further intended that pedestrian and cycle linkage be extended via a footbridge over the North Woolwich Road, connecting with proposed new housing areas and the GMEX centre and existing DLR station at the north side of Royal Victoria Dock. Plots have been reserved on three sides of the new Park for private residential development.

Contamination and site remediation

The client saw contamination as a major constraint, limiting the potential to reshape the site. However, after a fundamental assessment of the extent and degree of contamination, Arup was able to allay these concerns. The material could be moved around on site, allowing the site levels to be reprofiled and the vision of the design team to be realised.

The remediation design was based on 'hazard-pathway-target' risk assessment methodologies. 'Targets' at risk from the contamination ('the hazard') were identified - visitors to the Park, vegetation, building materials - and the 'pathways' linking the contamination to these targets were examined. The remediation strategy focused on severing these pathways to reduce the risk of harm to acceptable levels .

In practice, this strategy involved installing a land-drain to extract contaminated groundwater and removing relatively small volumes, or 'hot spots', of highly contaminated material like tars (Fig 4) for disposal off site. However most of the soil proved to have only low levels of contamination and could remain on site.

The potential linkage from contamination to Park visitors, vegetation, and building materials was broken by placing a crushed concrete capping layer over the recontoured soils. This layer was specified to contain only coarse-grained particles so that it would act as a capillary break layer, preventing any contaminated groundwater being drawn up into the overlying clean materials. A geotextile layer was then placed over the capping layer, serving the dual function of stopping fines migration compromising the capillary break layer and, equally importantly, acting as a signal layer. This is essential to the long-term maintenance of the Park, as the signal layer gives clear warning when future excavations are entering potentially contaminated ground, and where extra health and safety precautions should be taken.

Layers of clean, imported subsoil, topsoil, and hard surfacing materials were then placed to create the new Park. The thickness of these layers varies: up to 1.7m depth of soil was needed for tree roots, whereas grassed areas required a reduced thickness and hard paved areas less still. Trenches of clean material were also provided to accommodate service pipes and cables. The engineering design of the remediation layer levels was thus fully integrated with the architectural design.

The overall remediation strategy chosen for Thames Barrier Park was preferred over alternative solutions involving disposal of large quantities of material off-site or providing a 'blanket' capping layer over the contamination to permit the site to be developed for any use. This 'suitable for use' approach generated fewer traffic movements, dealt with the problem at source, and was economical. In this way the design is sustainable, and satisfied the requirements of the client, the local authority, and the Environment Agency.

This 'suitable for use' approach is now endorsed by the Government's Environmental Act Part IIA, which came into force this year.

6.
View along the riverside walkway.

Structures

The pavilion

The pavilion is in the north of the Park, close to the car park, and designed as two contrasting elements which follow the rationale of the accommodation. Fair-faced concrete walls and a concrete roof form the enclosure for toilets, storage, and services. The walls echo those used to form the 'green dock'. In contrast, the café structure is a lightweight timber and steel frame with a glazed wall set back under a deep overhang. The glazed wall opens out onto the timber terrace, providing panoramic views over the Park.

To preserve the remediation strategy, foundations for the pavilion were located above the recontoured site. The entrance to the Pavilion is an opening in a screen of vertical timber battens, set back under the edge of the concrete. The timber screen folds back to line the entrance corridor, which opens out into the café to frame the view of the Thames Barrier.

7.
The pavilion.

Bridges
To link the network of paths around the Park, bridges had to traverse its features. The larger bridges above the green dock have steel box beams as their principal structural elements; these also form their sides, and in one case the handrail. Although the box beams are 900mm deep they seem small in scale when compared to the green dock. In contrast to the solid sides of the bridges, the decks are formed of open mesh and timber, suspended on hangers from the beams. Again, the foundations for the bridges were located above the recontoured site levels to preserve the remediation strategy.

8.
View up the green dock towards the river.

9.
Memorial canopy.

Canopy
At the south end of the green dock is a memorial to the people of the London Borough of Newham who lost their lives in the World Wars. The canopy overflys this and forms a resting place adjacent to the river with views of the Thames Barrier. The architectural aim was the impression of a 'floating' plane at high level, and this is achieved by using a steel grillage to form the roof, and supporting it on steel columns apparently disposed at random. A construction sequence was devised to fabricate the canopy roof in two halves, requiring just two lifts to crane it into position. This was a successful strategy and the kit of parts fitted together exactly. The proposed riverside walkway passes below the canopy, linking it to the green dock.

Constructing the Park
Construction was in two phases. During the first, the remediation works were undertaken and the soils reprofiled, whilst the second phase consisted of planting new vegetation, building the structures, installing the water feature, and constructing the hard pavings. Supervised by Arup, Phase 1 began on site in January 1997 and was completed in nine months on time and within budget. Phase 2 took longer due to planting requirements, and was not completed until March 2000. After an initial period to allow the planting to 'bed down', the Park opened to the public in September 2000.

Notably, the measures adopted by the contractor to deal with contamination on site were neither restrictive nor expensive. He opted to erect a fence around the whole site and class it as 'contaminated'. Persons entering the contaminated area were required to pass through a 'decontamination unit', which provided washing and clothes changing facilities. Similarly, vehicles leaving the site had to pass through a wheel wash to prevent contamination being taken off site. Activities such as smoking and eating were banned in the contaminated area and workers were given a full induction into the nature of the site and the safe working practices that should be adopted. The health and safety risks were further reduced by the contractor excavating and filling the contaminated material in small areas at a time, and by using water dowsing to control dust generation. These measures were approved of by the local Environmental Health Officers.

Long-term ownership, operation, and maintenance
Following the demise of the LDDC, the project was taken over by English Partnerships, who have seen the construction phase through to completion and will maintain the Park for the first three years. After this initial period its ownership and maintenance will be handed over to the London Borough of Newham, who formed part of the original client team and were fully involved in the design process. They have exciting plans for the Park and are committed to its upkeep.

Catalysing regeneration of the surrounding area
As proof that high quality, public urban space plays a key role in creating successful urban areas, the Thames Barrier Park - even at the time of its official opening - is already having a significant positive effect on the surrounding area. The housing plot to the west was sold to Barratt Homes in 1998 and construction of the residential units - 'Millennium Point' - is well advanced. Much of this development has already been sold in advance - the attraction of living directly adjacent to a park being a significant factor in making it one of the fastest selling new housing developments in London. The first residents moved in at the end of 1999 with more moving in during March 2000.

The development of 'Britannia Village' to the north east is also progressing, adding more affordable housing, a primary school, and shopping to the area. The proximity of public open space near to these houses will obviously be a key factor in helping the community to develop.

There is a noticeable 'ripple effect', with development activity beginning at other nearby sites. Tanks and buildings on the adjacent Gulf Oil site to the west of Thames Barrier Park (now owned by Shell), have been dismantled and a planning application is expected to be submitted within the coming months for a mixed use development . An outline planning application has been submitted for redevelopment of a scrapyard site to the east of Thames Barrier Park into housing and interest is also being shown in regenerating other sites in the vicinity.

With further development of Canary Wharf increasing the employment opportunities in the area, Thames Barrier Park provides an important focus for residential development. In accordance with the recommendations of the Urban Task Force[2] and proposed changes to planning guidance from central government, much of this residential development is likely to be medium-to-high density, and with this, Thames Barrier Park will be an important and well-used area of open space and greenery for the local community. The idea of creating a publicly-funded open space with surrounding private housing is a model which can be copied when redeveloping more of this area.

Conclusion
Thames Barrier Park clearly demonstrates the benefits of integrating engineering with landscape design. Good urban design, which recognises the importance of public space, together with the implementation of appropriate and affordable engineering solutions to brownfield problems, can initiate the successful regeneration of derelict urban areas. The project is an excellent example of how relatively small amounts of public spending on 'community' projects can prime large private investment to revitalise such neglected urban areas.

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(2) URBAN TASK FORCE. Lord Rogers of Riverside, Chairman. Towards an urban renaissance. Final report of the Urban Task Force. E&FN Spon, 1999.

Credits

Clients:
London Docklands Development Corporation (subsequently English Partnerships)
London Borough of Newham

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Groupe Signes / Patel Taylor

Engineers, Environmental Consultants and Planning Supervisors:
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Illustrations:
1, 6-9: Arup / Patel Taylor
2: English Partnerships
3: Groupe Signes / Patel Taylor
4, 5: Arup

Yannawa Wastewater Project, Bangkok, Thailand

John Senior

Background

Thailand: one of the 'tiger' economies of East Asia in the late 1980s and early 1990s.

The capital, Bangkok: a vibrant metropolis of some 10M people, experiencing rapid urban growth as people from rural areas gravitate inward to share the benefits of the expanding economy.

The result: a huge burden on the Bangkok Metropolitan Administration (BMA), to rapidly provide the necessary infrastructure to meet the ever-increasing demand.

Fortunately, the buoyant economy also enabled solutions, with internal finance being raised for many major projects to address some of the crucial issues. These included elevated and underground rail systems to alleviate traffic congestion; flood defence bunds and improved drainage pumping installations to mitigate flooding from the Chao Phraya River; and environmental improvement projects to reduce water-borne disease by collecting and treating wastewater.

This article describes one of the major environmental improvement projects: the Yannawa wastewater collection system and treatment plant serving a 30km^2 area of Central Bangkok (Fig 1).

1.
The Yannawa Project area in central Bangkok.

2.
Khlong Sathern, with manhole in the foreground indicating sewer routing.

Existing situation

Bangkok is known as 'the Venice of East Asia' because of its multiplicity of canals or khlongs (Fig 2). Most of the land - reclaimed from the deltaic flood plain of the Chao Phraya River - is low-lying and flat, and the combination of high lunar tides and heavy rainfall can result in regular flooding, during which the khlongs serve as attenuation storage basins.

Like Venice, the city of Bangkok suffers from widespread regional settlement, due to consolidation of the subsoil by reduction in piezometric profile from ground water abstraction. The current rate of settlement in central Bangkok is between 10-30mm/year. All major structures are founded on deep friction piles in the overlying clay, so roads and footpaths have to be raised at regular intervals to maintain levels with the adjacent buildings. Underground services become deeper with the placement of this additional fill.

The commercial districts' combined storm and foul drainage system discharges directly into the khlongs. The flat terrain and high khlong water levels prohibit adequate pipe gradients, and differential ground movement further exacerbates the resultant solids settlement. Although the BMA undertakes a major pipe cleaning operation every year, immediately before the rainy season, the khlongs - also used for water transport - had become open sewers, devoid of aquatic life, emitting odours, and posing a major health risk to the local community.

The project

In 1994 the BMA requested bids from international consortia to design and construct the Yannawa Wastewater Project, serving a population of approximately one million.

The project provided for: the interception of all foul sewage flows prior to discharge into the khlongs, a piped transmission system to convey these flows to a central treatment plant; the construction of the first phase of a nutrient removal treatment plant; construction completion within three years; a further 12 months' operation and maintenance and finally the training of operators.

Arup was appointed as designer for the bid submission by a Korean/Thai consortium comprising Samsung Engineering &Construction Co Ltd (Korea), Lotte Engineering & Machinery MFG Co Ltd (Korea), and the Civil Engineering Co Ltd (Thailand). Arup in turn retained Earth Tech Engineering (UK) as specialist process sub-consultant and Epsilon (Thailand) as specialist architectural and environmental impact advisor. In July 1995, the BMA completed its technical and financial evaluation of bids, and awarded the project to the Samsung Lotte CEC JV for a contracted sum of US$180M. Arup, Earth Tech, and Epsilon were retained for the detailed design.

There was an eight-month delay caused by the prolonged relocation of informal settlers from the treatment plant site, and the 1997 economic crisis also intervened. However, after successful performance testing, the project was officially opened on Tuesday 14 December 1999 by the Governor of the BMA, Khun Bichit Rattakul, to a fanfare of full national press and TV coverage.

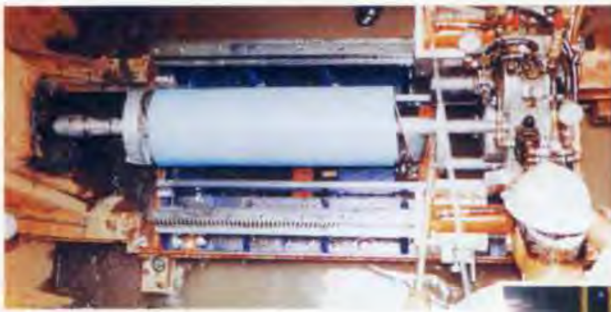
Yannawa is the first major environmental project to become operational in Bangkok. All other wastewater projects have been significantly delayed by contractual, technical, and land acquisition problems.

Wastewater collection system design

Inspection

During the bid period, detailed visual inspections were made throughout the area to identify all existing sewers, directions of flow, and potential routes for the new collector system pipes.

This served to reduce contractors' risk from later provision of unidentified additional pipe runs. Prior to detailed design, the entire area was surveyed and the catchments contributing to each sewer run accurately defined.



3.
Direction drilling for small diameter pipe.

Interception chambers / overflows

Each chamber had to intercept all the foul sewage flow during the dry season (ie dry weather flow, or DWF, and up to 5DWF during rainfall events. Flows in excess were to be overflowed to the khlong after primary screening in the chamber.

Bangkok is subject to high intensity, generally short-duration rainfall causing frequent local flooding, so the interceptor chamber design also had to minimise the head losses within the chamber that would have resulted in increased flooding upstream. A computerised model was prepared of the existing pipe network and a 10-year storm routed through the system to accurately define the storm flows to be catered for in the chamber. DWF was also computed for the contributing catchment. Existing adjacent services prevented the adoption of the large, conventionally designed controlled storm overflows used in the UK.

The small footprint chambers incorporated a drop into an orifice-controlled outlet pipe at the head of the new collector system. During rainfall the orifice created a predetermined back up in the chamber, allowing the surplus flows to overflow via a stainless steel screen into the adjacent khlong, whilst simultaneously controlling the inflow to the new collector system.

4.
2.25m diameter pipe jack being lowered into excavation.

Design considerations

Several significant factors were identified at an early stage:

- Records of BMA's sewers were incomplete, as were plans of other utility services, so a detailed inspection had to be carried out to define the extent of the works required.
- The construction period was very short, so fast track approval and construction methods had to be used.
- The complexity of other existing services and the lack of structured service routing precluded large, conventional, controlled storm overflow structures being adopted.
- Because new roads, new khlongs, and overhead and underground railways were also being built, close co-ordination was essential with other contractors in the area, all of whom were vying to use the same service route corridors.
- Open trenching in the soft Bangkok clays necessitates continuous sheet piling, with the added complication of significant surrounding ground settlement due to excavation, with possible damage to adjacent buildings. Traffic disruption from open trenching would have been unacceptable, and trenchless pipelaying techniques proved both economically viable and environmentally preferable.
- Traffic congestion prohibited working on major road routes during the day, but night-time working, with associated daily establishment and reinstatement, would have been unacceptably expensive and would slow implementation.
- Construction nuisance - noise, air, and water pollution - had to be minimised.
- To avoid delays through land acquisition, only land owned by the BMA could be used.
- The whole area was subject to the 20mm pa land settlement, and differential settlement problems between piled and unpiled structures had to be carefully addressed.
- The high land values dictated that the available sewage treatment plant site was less than 3ha, of which 50% was within the tidal zone of the Chao Phraya River and occupied by the informal settlers in elevated housing on timber piles. A conventional treatment plant would require a site area of approximately four times that available, and would be visually unacceptable in this central city location.
- The wastewater treatment plant had to blend in with the adjacent prestigious commercial / residential river frontage properties and cause minimal environmental nuisance.
- The absence of an integrated collection system prohibited accurate composite sampling to assess daily / annual variance in wastewater influent, necessitating maximum flexibility in the design of the treatment plant to cater for widely fluctuating flows and strengths.

Sewer construction techniques

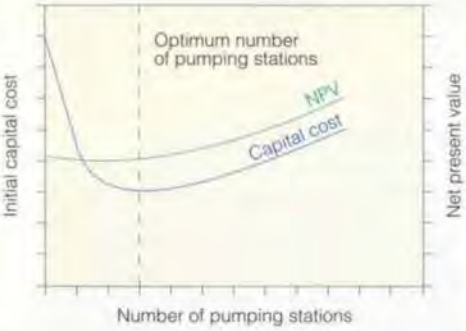
The soft Bangkok clay, to a depth of 15m, was ideal for using a combination of trenchless pipelaying techniques, including directional drilling for smaller diameters (250-450mm) (Fig 3); microtunnelling for intermediate diameters (600mm-1m); and semi-shield pipe jacking for most of the network with larger diameters (1.2-2.25m) (Fig 4). Over 90% of the 51km of sewers were ultimately built by these techniques, with jacking distances achieved up to 200m in each direction from the jacking pits. Jacking and receiving pits were built with braced sheet piles up to 12m deep, and concrete caissons for deeper pits. Manholes were incorporated within these pits as part of the final collector system.

Sewer routing

The decision to use trenchless pipelaying, combined with the restriction on daytime working along primary roads, made routing the sewers below the bed level of the multiplicity of khlongs the best solution. This brought with it the advantage of giving the contractor space to work above and within drained portions of the khlongs, on land owned by the BMA. Interference from existing services was also minimised along the main routes.

Sewer design and modelling

All wastewater collection systems are hydraulically interactive, and small changes at one location can cause unacceptable spills elsewhere. In a heavily developed area like Yannawa, changes to preferred sewer routes were inevitable, due to unexpected obstructions, road closures, traffic re-routing, other contractors' new works, unexpected difficulties associated with access, etc.



5.
Sewer optimisation graph.


6.
Collector system pumping station built over khlong.

Any such changes needed to be rapidly and comprehensively evaluated, and solutions devised to minimise contractors' standing time.

The sewer design was, therefore, completely computerised, utilising a project-specific, in-house spreadsheet program for sewer sizing. This automatically fed into the Wallrus hydraulic modelling program (developed by Hydraulics Research Institute, Wallingford, England) which permitted detailed modelling of the network, and in turn generated long sections along all sewer routes, in AutoCAD format. All this allowed initial evaluation of many options for sewer optimisation, and, during detailed design, rapid evaluation and drawing of revisions requested from site.

Sewer optimisation

Preliminary collection system designs were prepared for various combinations of pipe size, depth, and number of pumping stations. Sewer depths were limited to a maximum of 15m as jacking in the stiffer clay could have severely restricted jacking distances. Increasing the number of pump stations permits shallower pipes or steeper grades, and reduces pipe size. However, although this reduces pipelaying and manhole construction costs, it increase operational costs. Net present value analyses, over the 50-year design life of the scheme, revealed the most cost-effective solution (Fig 5), and three major pumping stations were ultimately adopted, within the collector system.

Collector system pumping stations

Selecting the most appropriate type of pumping station was predominantly based on the availability of BMA land in the place chosen for each station. The only practicable solution was to build the stations within the khlongs, with the wet well below khlong bed level and the motor control centre, transformers, forced air ventilation, and support facilities above the khlong (Fig 6).

This interrupted neither the khlong water flow nor the water taxi traffic. However, doing this posed further challenges: access to pump sets for maintenance: satisfactory hydraulic layout, accommodating pump sets with a combined capacity of up to 8m^3/sec/station within a relatively narrow 6m wide khlong: and avoidance of pollutant spills during prolonged periods of power failure.

The accessibility issue was overcome by selecting submersible pumps that could be lifted to ground level for maintenance via shafts in the footpaths by the khlong. Access to the wet well was also achieved by a similar dedicated shaft for man access. An iterative process of physical pump station model testing and layout modification ensured that satisfactory hydraulic feed to the pumps was achieved, under all anticipated flow conditions.

The power failure problem was overcome by adopting a gravity discharge outlet launder (channel). Under normal operation, pumps lift into an outlet launder and the flow gravitates downstream. The pump stations have a rated capacity of 5DWF, but if the power fails for any length of time, flow backup in the incoming sewer ultimately overflows a weir into the outlet launder and gravitates to the treatment works, bypassing the pump wet well. The Wallrus computer model showed that if this occurs, approximately 3DWF could be passed through the collector system, preventing unacceptable pollution spills into the adjacent watercourses.

The pump stations incorporate isolating penstocks which both permit maintenance within the wet well and allow gravity bypass of the station - albeit with upstream sewer surcharge. Coarse screens are also provided for pump protection.

The wet wells are ventilated by a forced, natural air, entry-exit fan system; both internal and external gas concentrations were found to be well within the client's specified requirements.

The pump station control system is based on networked programmable logic controllers (PLCs) operating in conjunction with a remote supervisory, control and data acquisition (SCADA) system which displays and records pump operation and operating water levels in a central control room at the wastewater treatment plant.

All three 20m deep lift stations were built within diaphragm walls below khlong bed level, which also support the conventional column and suspended slab buildings above the khlong.

Wastewater treatment plant

The treatment plant site only covers 28 000m^2, of which around half was subject to daily flooding from the Chao Phraya River. The site's northern boundary adjoins one of the major khlongs, Chong Nonsee, whilst to the west and south it abuts land owned by the King of Thailand and other private development. Obtaining more land was not, therefore, possible (Fig 7).

The nearness of the river and the khlong, and the extremely poor ground conditions, precluded an expensive below-ground basement structure, because of potential risks from flooding before completion of the flood defence walls. At the same time the treatment process had to be carefully selected, due to the space limitations, the need for a treatment plant structure that blended into its surroundings, the elimination of environmental nuisance, and the flexibility to receive and successfully treat a wide range of influent strengths and flows from a combined wastewater collection system. Clearly, typical greenfield treatment options would not fit on the site and would be environmentally unacceptable.

7.
Plan of wastewater treatment plant.

8. The treatment plant.

A decision was made at bid stage to go for a multi-storey plant (Fig 8) using sequential batch reactor (SBR) technology. This eliminates the need for both primary and secondary settlement tanks, and its positive advantages include: savings on land requirements, readily available enclosed areas for air extraction and associated odour control, compatibility with surrounding development, ease of construction from repetitive use of formwork, and cost savings associated with piling in poor ground.

It was recognised that additional operational costs were inevitable as a result of pumping some of the sewage to higher elevations for treatment, but net present value analyses indicated that this form of construction was extremely cost-effective in comparison with conventional plants, particularly if both roofing (for odour control) and land value costs were incorporated into the analysis.

Furthermore, it became even more cost-effective if pumping costs to alternative, larger, more remote sites were included.

9. Inlet pumping station.

Treatment capacity

The terms of reference required a treatment plant design to cater for:

- an ultimate full treatment capacity of $1Mm^3$/day
- a preliminary treatment capacity of $2Mm^3$/day
- treatment of $1000m^3$/day of night soil.

The Phase 1 construction provided for:

- a full treatment capacity of 300 $000m^3$/day
- a preliminary treatment capacity of $1Mm^3$/day
- treatment of $1000m^3$/day of night soil.

Treatment standards

The requisite treatment standards are:

- biochemical oxygen demand (BOD) <20mg/l
- suspended solids (SS) <30mg/l
- total nitrogen <10mg/l
- ammoniacal nitrogen < 5mg/l
- phosphorus < 2mg/l
- dissolved oxygen > 5mg/l

Inlet pumping stations

There was no room on the small site for a large single-inlet pumping station to lift the flows from the twin 2.25m diameter incoming sewers to ground level for treatment, so two smaller stations, each using submersible pumps for compactness, were constructed:

- inlet pumping (Fig 9), to lift flows for full treatment and to spill surplus flows to:
- storm pumping, which lifts surplus storm flows for preliminary treatment prior to discharge to the river.

Interconnecting pipework permits transfer of flows to either full or preliminary treatment from either station. This configuration gave extra flexibility, allowing each station to be decommissioned for maintenance / expansion whilst continuously maintaining flows to full treatment.

Storm flow treatment inlet works

Surplus storm flows are fed through the storm flow measuring flumes before preliminary treatment, through 12mm rotating bar screens. Screenings are mechanically raked into a launder channel and conveyed to two twin-screw compactors which discharge the screenings into skips. Treated flows are discharged to the river.

Full treatment inlet works

The inlet pump station feeds into an elevated launder channel, incorporating the full treatment measuring flume. The principal feature of the inlet works is the use of dynamic separation to remove grit particles down to 0.2mm and coarse screenings. The vortex action, in two 8.5m diameter separators, draws non-biodegradable material to the centre of the tanks where it is pumped to a laundering system which transfers the grit and screenings via conveyors to skips (Fig 10).

The treated flows are passed through two fine band screens for removal of screenings down to 5mm, before moving on to secondary treatment. The total inlet works footprint occupies 25% of the area normally occupied by conventional preliminary treatment design.

Secondary treatment

Secondary treatment utilises Earth Techs' CASS™ process (cyclic activated sludge system), which is a variant of SBR technology. The process employs single tank aeration systems, which require neither primary sedimentation nor final settlement tanks and is ideally suited to sites with space restrictions. The CASS™ process was chosen because of its intrinsic flexibility to meet the stringent final effluent requirements including nutrient removal, whilst accommodating a wide variation in hydraulic and organic influent load. The wisdom of this choice was proven at Yannawa, where the actual influent is significantly weaker in organic load and higher in dissolved oxygen content than expected.

The process has consistently achieved the required effluent standard.

The secondary treatment process - a total of four basins and 24 associated compartments - resides on four floors of the multi-storey structure. Each floor has one basin in the CASS™ system, comprising six 60 x 18 x 5m deep compartments, three either side of a central gallery.

The latter accommodates the flow distribution chamber, CASS™ feed pumping station (Fig 11), distribution pipework and, on the upper floors, electrical equipment, blowers, and staff facilities.

Process air is provided by positive displacement blowers coupled to a fine bubble diffused air system (Fig 13), which is automatically controlled by dissolved oxygen probes linked to the automatic control system. Final effluent from the basins passes down two vertical drop shafts and is discharged to the river after passing through a re-aeration cascade.

10. Inlet works.

11 below:
Delivery pipes from CASS™ pump station in central gallery.

Treatment process

The CASS™ process combines a biological selector and a variable volume process reactor, and operates with a single sludge in a single reactor basin to accomplish both biological treatment and full solids separation. The process is configured to function with filamentous sludge bulking control to achieve biological nutrient removal. A simple repeated sequence of aeration and non-aeration is used to provide sequential aerobic, anoxic, and anaerobic conditions which, in combination with the aeration intensity, favour nitrification, denitrification, and biological phosphorous removal. The essential features of the process are the plug-flow initial reaction conditions and complete mix reactor basin (Figs 13 & 14). Each compartment is subdivided by baffle walls into three sections:

- *Zone 1:* selector zone
- *Zone 2:* secondary aeration zone
- *Zone 3:* main aeration zone

Sludge biomass is continuously recycled from Zone 3 to Zone 1 to remove the readily degradable soluble substrate and to encourage the growth of the floc forming micro-organisms. Careful selection of the sludge return rate makes the biomass cycle approximately daily in the main aeration zone through the selector zone. The mechanisms of Zone 1 and the internal sludge recycle eliminate the requirement for separate fill-ratio selectivity, anoxic, and aerobic mixing periods. The selector is self-regulating for any load condition and operates under anoxic conditions during aerobic periods and anaerobic reaction conditions during non-aeration periods. Polishing denitrification and enzymatic transfer of available substrate during enhanced biological phosphorous removal is also achieved in the selector zone.

The complete mix nature of the main reactor provides flow and load balancing and a tolerance to shock or toxic loading. The process prevents solids washout during peak hydraulic surges, and uses a simple, repeated, time-based sequence: *1. fill-aerate 2. fill-settle 3. decant.*

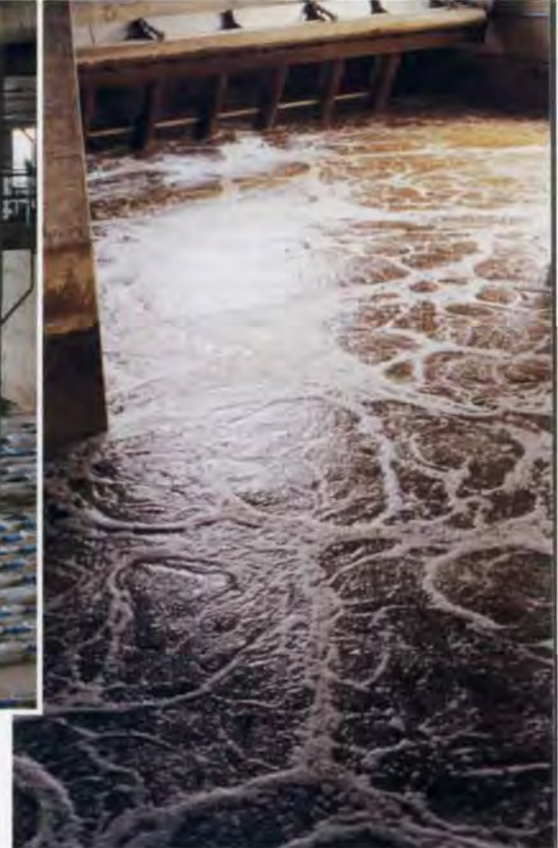
During fill-aeration, the liquid level rises in the reactor basin from a set bottom water level, in response to the varying inflow rate. Influent comes into the basin through the selector zone, where it contacts with the sludge biomass recycled from the main aeration zone. Air-assisted, complete mix reaction conditions occur in Zone 3 during this variable volume operational period.

The fill-settle operation occurs during the air-off period, creating quiescent settling conditions in Zone 3 for solid / liquid separation. At the end of the aeration period the basin contents are thoroughly mixed, to uniform concentration. During initial settling, the sludge undergoes internal flocculation due to the residual mixing energy within the basin. As this energy dissipates, the sludge interface forms and settles as a blanket, leaving a clear supernatant at the surface; dense solids fall through the formed mass to settle on the basin floor. Initially, the settling velocity is quite slow, then increases, then gradually falls off, due to the compressive accumulation of solids on the basin floor. During the fill-settle cycle the biomass continues to be recycled to the selector zone to create anoxic / anaerobic conditions.

13.
Treatment basin, showing bubble aerators.

The inflow to the basin is interrupted during the decant period, and the flows are diverted to an alternative basin. The drawoff weir - parked above top water level during the fill-aerate and fill-settle cycles - is lowered at a controlled rate and the clear supernatant is drawn off at a constant rate. When the water levels fall to the predetermined bottom water level, the weir is raised above top water level to the park position ready for repetition of the cyclic operation. Surplus sludge is wasted as required to maintain the required biomass MLSS (mixed liquor suspended solids) concentrations in the basins.

During the commissioning and subsequent operations period, the inert fraction was found to be low (around 30%), whereas for 'normal' domestic sewage the inert fraction is usually around 60-70%. The reactors are now operating at higher MLSS concentrations than envisaged, and the balance between maintaining the required MLSS to ensure nitrogen removal whilst avoiding excessive sludge age is achieved by careful control of surplus sludge removal.



14.
Treatment basin in aeration cycle.

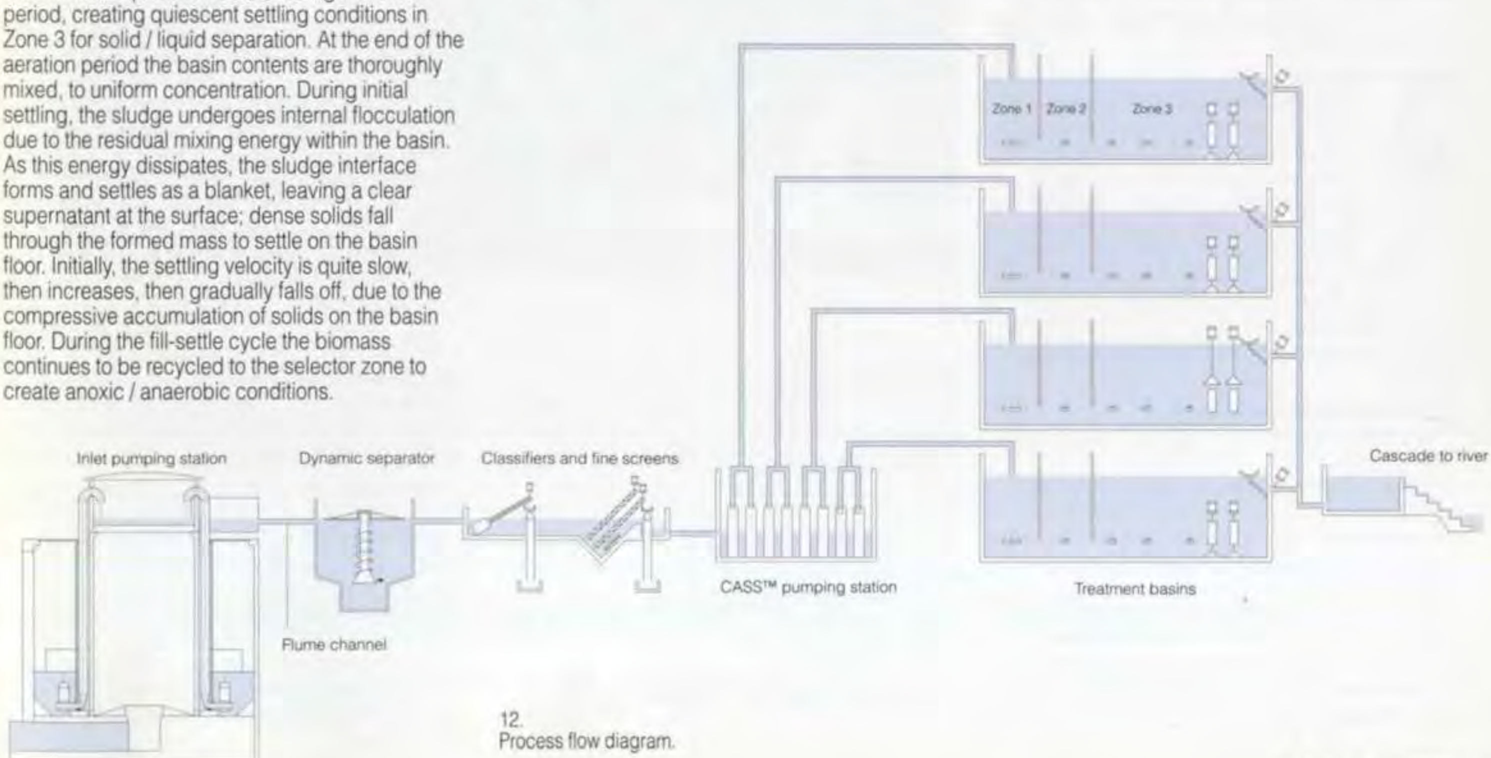
Sludge handling and disposal

Surplus activated sludge is pumped from the basins to the aerated buffer tanks prior to polymer addition, dewatering, thickening in belt presses, conditioning with lime, and conveyance to storage bunkers for ultimate disposal on land.

Night soil treatment

BMA tankers deliver night soil (septic tank sludge) to the treatment plant site, where it is screened and degritted before discharge into two 500m³ holding tanks.

The intrinsic flexibility of the plant allows several treatment options: combination with the surplus activated sludge prior to thickening and dewatering; separate thickening and dewatering; or diversion to the CASS™ process for full treatment.



12.
Process flow diagram.

15. Chemical scrubber for odour control.

16 above: Laboratory for sampling and process monitoring.

17 left: SCADA instrumentation and control room.

18 below: Treatment plant seen from Khlong Chongnonsee.

Odour control

The building enclosure readily contains odours generated in the inlet pump station, inlet works, and sludge handling areas. These gases are conveyed, via a ducted extraction system, to a multi-stage wet chemical scrubber for treatment before discharge through a high level stack to ensure nothing reaches the surrounding residents (Fig 15).

The treatment basin design incorporates natural cross-flow ventilation through strategically sized openings in the building's external façade, thereby eliminating the need for large-scale collection and treatment of air from around the basins. Operating the treatment plant has revealed minimal odour emission from the CASS™ basins, and the decision to adopt natural ventilation has been fully justified.

Instrumentation control and automation

The plant relies on simple, easily automated control routines, devoid of the complications often associated with using new technology in developing countries. As with the pump stations, the control system is based on networked PLCs operating with a SCADA system which displays and records plant operation in a central control room (Fig 17). A high level of simple and reliable process instrumentation is provided to facilitate automatic control of the process plant.

Wastewater recycle

Treated effluent is utilised for washdown water in the plant and also to supply BMA tankers for irrigation of landscaped areas throughout the surrounding district.

Support facilities

A two-storey administration complex has been constructed above the Inlet works and this comprises a library, training / conference rooms, offices, and a fully equipped laboratory (Fig 16) for sampling and process monitoring. The motor control centres, SCADA room, and HV switchgear are also accommodated in this complex. Showers and changing rooms for technicians, supervisors, and operators are on the top floor of the central gallery. Workshops and equipment stores are in a separate single-storey building on the treatment plant site.

Treatment plant buildings

The structural design of the treatment plant faced a challenging set of circumstances:

- poor ground conditions giving potential for large settlements, even with very deep foundations
- a combination of heavily and lightly loaded structures and deep underground pumping stations, all in close proximity
- extensive services crossing structure interfaces, with little tolerance for differential settlement
- the requirement for maximum space saving
- co-ordination of structure with a multiplicity of services.

These necessitated a completely integrated approach to the geotechnical and structural design.

Early on the contractor expressed his preference for in situ reinforced concrete construction, making maximum use of locally available materials.

The Phase 1 treatment plant buildings occupy an area of 12 000m^2 and, in terms of structural design, are divided into five distinct sections:

1. inlet and storm pumping stations
2. inlet works and associated administration facilities
3. central gallery
4. north and south treatment basins
5. workshops, stores, and nightsoil tanks.

The inlet and storm pumping stations are 20m diameter, 20m deep structures, constructed within diaphragm walls with in situ annular rings and internal suspended slabs.

The inlet works is a geometrically complex structure housing the dynamic separators, screen units, compactors, and many connecting ducts, conveyors, and overflows at different levels. The upper part houses the administration areas. Although relatively lightly loaded, the structure is founded on 1m diameter bored cast in situ piles some 50m deep, making its founding conditions similar to adjoining heavily loaded structures and thereby mitigating differential settlement across the interface.

19.
Central gallery of treatment plant.

20 below:
Staff training.

The central gallery (Fig 19) between the treatment basins - housing the distribution pumping station, delivery pipework, electrical equipment, blowers and staff facilities - is relatively lightly loaded compared with the adjacent basins but to mitigate differential settlement it was given the same type of foundation, albeit on a wider grid.

The 5m depth of water in the six 60 x 18m treatment basins on each of the four storeys makes the 35m high structure weigh more than a 20-storey office building. Its foundation is a 4.5 x 4.5m grid of 1.5m diameter, 55m deep, bored piles, each with a design load of 10MN, but even with these, the combination of Bangkok's geology and the large basin loads still meant that total settlement of up to 200mm could be expected at the centre of the basin footprint, diminishing to 100mm at the edge.

This differential settlement posed considerable problems for the design of the basin structure.

The basins are of in situ concrete, designed to water-retaining codes to limit crack widths. They are not tolerant of cracking, and using joints and articulation within each basin was not possible due to the process engineer's requirement for long, deep-sided tanks.

Although the basin walls are an integral part of the structure, large openings are needed above top water level to maximise ventilation and avoid the build-up of dangerous gases. This resulted in a vertical sequence of stiff tank walls sandwiched between more flexible sections. The tendency for the foundation settlement to impose a 'dished' deflection profile on this system gave rise to an unusual distribution of stress in the walls and piers which the design had to accommodate to avoid local failures and cracking.

The basins' large footprint gives their settlement a wide zone of influence which encompasses all the other structures in the vicinity. Although the differential settlement across the treatment plant may approach 100mm, the profile is relatively gentle, and founding the lighter-loaded structures at the same depth ensured that step changes in settlement at the critical interfaces were avoided.

Commissioning

Pre-commissioning checks commenced in August 1999, when part of the wastewater flows were first transferred to the treatment plant. Initial concerns related to the very low strength of the incoming sewage, inhibiting the rapid generation of the MLSS concentrations necessary for denitrification. Various supplementary measures were considered, such as adding seed sludge, and an initial reduction in the numbers of operational basins. Process stabilisation was further hampered by the need to demonstrate to the client that all items of plant were functioning satisfactorily; this occasionally resulted in extended downtime periods while individual items of plant were both dry- and wet-tested.

Despite these factors, final performance testing commenced on time in November 1999, using nine compartments to treat the entire incoming (dry season) flow. The requisite final effluent standards were successfully achieved in the one-month commissioning period. Since that time, both the influent flow (after the onset of the rainy season) and sewage strengths have increased, and the plant continues to achieve the final effluent standards, using more treatment compartments.

Operation, maintenance and training

Both Arup and Earth Tech staff have been heavily involved in preparing operation and maintenance manuals, and training the largely inexperienced workforce (Fig 20). Staff remain on site at the time of writing both to provide a trouble-shooting advisory service and to supervise the operation of the plant and collector system.

Conclusion

The Yannawa project sets new standards in terms of successful multi-national co-operation between Thai, Korean, British, American, Australian, and German plant suppliers, contractors, designers, and supervisors. The collector system constitutes one of the largest trenchless pipelaying contracts yet undertaken, and the advanced technology, small footprint, treatment works is certainly the largest multi-storey nutrient removal plant constructed in the world.

Reference

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Credits

Owner:
Bangkok Metropolitan Administration

Owner's representative:
Metcalf & Eddy / Thai Engineering Consultants (TEC)

Client and main contractor:
Samsung Lotte CEC Joint Venture

Designer:
Arup Kate Aplin, Rachel Bentley, Mark Bidgood, Gill Brazier, Rebecca Brown, Sue Burton, Ian Carradice, Ebrima Cham, Steve Cliff, Phil Cole, Jacki Collison, John Davies, Liam Delaney, Tony Dunbar, Robin Foster, Julie Herrington, Paul Geeson, John Harvey, Anke Kratz, Rhodri Lea, Robin Lee, Geoff Lewis, Peter Matson, Barry McAuliffe, Duncan Overy, Roger Pickwick, Nick Rabin, John Read, Jon Roberts, John Senior, Ken Sharp, Sarah Simms, Martyn Stroud, Peter Terry, Julian Thew, Paul Thompson, Paul Tonkin, Alan Turner, Chris Webb, Bob Williams

Process sub-consultant:
Earth Tech Engineering Ltd

Architect:
Epsilon Architect Co. Ltd

Illustrations:
1, 3, 20: Arup
2, 19: Paul Thompson
4: McConnell Dowell
5: Ben Davies/Penny Rees
6, 8, 9, 13, 16-18: John Senior
7, 12: Martin Hall
10, 11, 14, 15, 21: Martyn Stroud

21.
The outfall cascade to the river, on the official opening day, 14 December 1999.

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