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Front cover:
Lille TGV station roof and façade (Copyright SNCF - Direction de l'Amenagement/Michel Denancé)

Back cover:
Satellite image of the Thames and London (Photo: Department of Transport/Engineering Surveys)

Euralille is a massive trade centre at Lille in north east France, whose construction was brought about by the selection of that city as the hub of the Paris-London and Paris-Brussels TGV rail lines. Amongst several Arup commissions connected with Euralille, the firm was appointed to design the structure and cladding for the roof and façades of the new TGV station constructed as a central component of the complex.

Ove Arup & Partners Newcastle designed the structure for this eight-span tubular steel arch bridge, conceived as the visual focus of the new tidal barrage which is a key feature in the regeneration of a derelict former engineering works at Stockton-on-Tees. The design deliberately recalls and celebrates the area's importance in the history of iron and steel engineering.

Arups were asked by the Government Office for London to undertake a detailed study of 50km of the Thames, from Hampton Court to Greenwich, in order to make recommendations for enhancing the riverfront environment, protecting areas of historic importance, promoting high quality new buildings and landscaping, and generally improving access and amenity.

This new privately-financed immersed tube road tunnel is the third link between Hong Kong Island and the Kowloon mainland. Ove Arup & Partners Hong Kong are acting as the Western Harbour Tunnel Company's project co-ordinators, with responsibility for overseeing the work of the contractors and design consultants as well as liaising with Government and other bodies involved.

Ove Arup & Partners Manchester carried out the structural engineering design of this conversion of the former Lewis's store on the seafront at Blackpool, next to the Tower, into a mixed-use trading/leisure building. The project included the creation of a new 2400m^2, two-storey space at the building's heart.

Through careful attention to layout, lighting, finishes, and security, this award-winning building has been described as setting new design standards for safety and convenience of customers. Ove Arup & Partners Newcastle were responsible for the project management and the structural, civil, and building services engineering design.

Euralille: the TGV station roof

Sophie Le Bourva
Jane Wernick

Amongst several commissions stemming from the masterplan for the Euralille centre (see 'Background' below), Ove Arup and Partners International Ltd. were appointed as the *Maître D'oeuvre particulier* for the roof of the TGV station, including the structures, the façades and the cladding. This contract was for an 'M2 plus' mission, which meant in effect a prime agency role for all phases of the work from concept design to completion. In the development of the structural design for the roof, Arups worked closely with French Railways (SNCF). RFR were sub-consultants for the design of the roof covering. The station is on the left of the aerial photograph below, straddled by the boot-shaped Credit Lyonnais and World Trade Centre buildings. To the right is the large wedge-shaped Euralille Centre, and in the distance on the right the oval Grand Palais.

1.

Background

Robert Pugh

Origins of Euralille

Lille, in north east France, is the country's second largest metropolitan district, with some 1.5M inhabitants. Historically focused on coal mining and its attendant industries, this socialist heartland with a large immigrant population had high unemployment following the demise of its traditional industrial base.

Following the January 1986 agreement between England and France to build the Channel Tunnel, signed by François Mitterand and Margaret Thatcher in Lille itself, the Mayor of the city, Pierre Mauroy, saw opportunities for local regeneration flowing both from the Tunnel and from the northern European and cross-Channel TGV (Trains à Grande Vitesse) system launched at the same time. A former Prime Minister of France, Mauroy formed an association called 'TGV - Gare de Lille', mobilising the city and the region to canvass for the TGV route between Paris and the Tunnel. After furious lobbying, the then French Prime Minister Jacques Chirac announced in December 1987 that Lille had been selected as the hub of the Paris-London and Paris-Brussels lines. This rail-linked centre of gravity for Northern Europe's major cities thus became an ideal location for trade and commerce and for multinational companies, and the Mayor used the fact of the station to initiate the much larger and more ambitious scheme of Euralille.

A mixed private/public client body called SAEM Euralille was formed in spring 1988, and an architectural competition launched to masterplan the 70ha site identified for the new TGV station and associated commercial development.

The Dutch architect Rem Koolhaas with his firm, Office for Metropolitan Architecture (OMA), supported by Ove Arup & Partners, won the competition in November 1988.

Elements of Euralille

By the end of 1994, 250 000m² of new development and associated infrastructure, comprising the first phase of the masterplan, and including the new station, had been built (Fig.1). This comprised:

- The Euralille Centre - 100 000m² of commercial space for retail, recreation, office, and residential use, with underground parking for 3500 vehicles.
- The TGV station - c500m long, of which some 300m is covered by a steel and glass roof which allows the trains to be seen from the city; capacity 15 000 passengers per day.
- The World Trade Centre Tower - 20 000m² of office space.
- The Credit Lyonnais Tower - 15 000m² of office space.
- The Rue Corbusier Viaduct - 0.5km of elevated dual carriageway.
- The Lille Grand Palais - 50 000m² entertainment, conference, and exhibition centre.
- Multi-storey parking garages - 1500 spaces.

The TGV now links Lille with Paris and Brussels in an hour, London in two hours, and soon Amsterdam and Cologne in two hours (Fig.2). Lille has become, as Rem Koolhaas has described, a 'virtual city' of 100M people.

2. Lille as the hub of the TGV network.

Arups' involvement

Ove Arup & Partners have contributed to three aspects of Euralille:

- *Masterplan feasibility, design development, and developer specification:* (building, civil, geotechnical, fire, and traffic engineering).
- *Lille Grand Palais:* (building and geotechnical engineering).
- *TGV station.*

Arups' work on the masterplan and the Grand Palais will be described in a forthcoming *Arup Journal.*

History and architectural choices

The architecture of railway stations has a rich history. Their identity was created in the 19th century in the wake of the headlong expansion of steam railways when daring designers celebrated technology and architecture by using exposed structures to create a bold generation of train stations.

About 10 different station configurations were created in Europe and the United States in the 19th century, and remained in vogue for three or four generations. In the 20th century, however, there has been little innovation. In addition, the importance of train stations in cities decreased as a result of the degradation of the train's reputation as the world's fastest terrestrial means of transport. However, the TGV has reinstated this preeminence and, as the SNCF began to develop the network, the opportunity of reviving the old position of stations in cities was offered. It was the occasion for the SNCF to think again about what a station building should be, so under the impulse of the TGV and of its newly-appointed chief architect M. Dutthilleul, a charter for the railway architecture was produced in 1987.

Its key points were:

(1) Stations should look like stations, by referring to and using the existing archetypes as the background to the new designs.

(2) The archetypes should be expressed via a contemporary architectural vocabulary, expressing the construction techniques.

(3) Stations should make people dream.

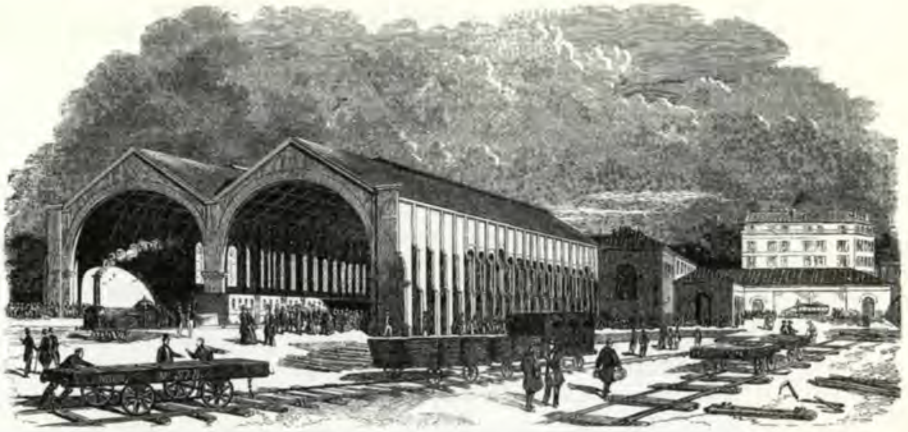
(4) Stations should remain in cities.

(5) The organisation of the station should be easily understood via its volume.

All this, as well as some more local factors, led to the main architectural aims for the Lille station:

- The station should be linked to the archetype of the Orsay Station in Paris (now Musée d'Orsay), i.e. it should be organised longitudinally, with the platform and the hall being part of the same volume, covered by a vast metal and glass roof.
- The station should be opened towards the city like a 'balcony' and be a showcase for the trains.
- Obstructions to passenger movement should be minimised and sightlines kept clear at concourse and platform levels. The space should remain as free as possible of structural supports.
- The roof should emphasise the quality of light in this northern region of France.
- The roof should be inspired by 19th century metal and glass roofs and be as close as possible to M. Duthilleul's ideal of 'a fine lace floating above the train'.

These initial intentions inspired the design decisions for the structures and cladding.



3. Another archetypal 19th century French railway station: the Gare du Nord, Paris, in 1847. The two bays shown still exist; the area into which the TGV trains now run was a later addition, to the right.

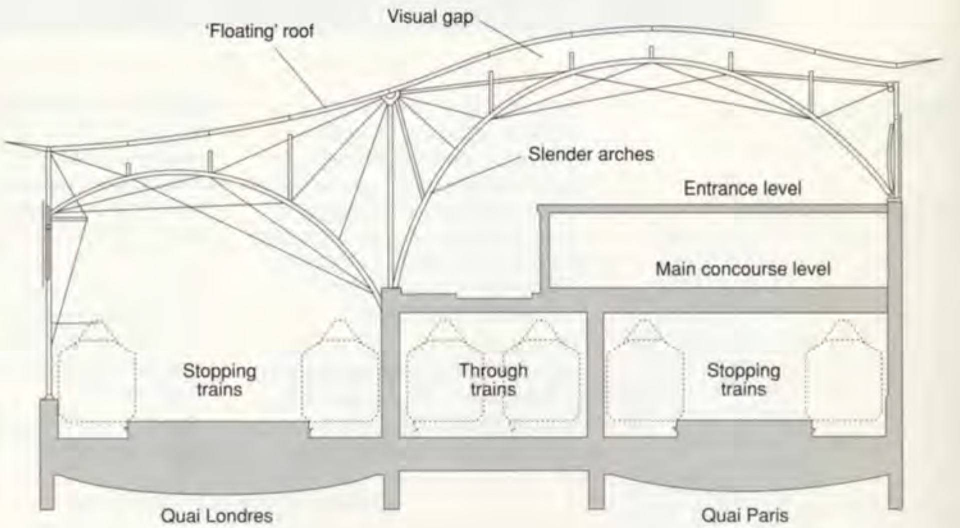
Various schemes were studied. The final design has a smooth, curved metal roof which seems barely to touch the transverse arches supporting it, the intention being that the roof should appear to float above the station like a flying carpet.

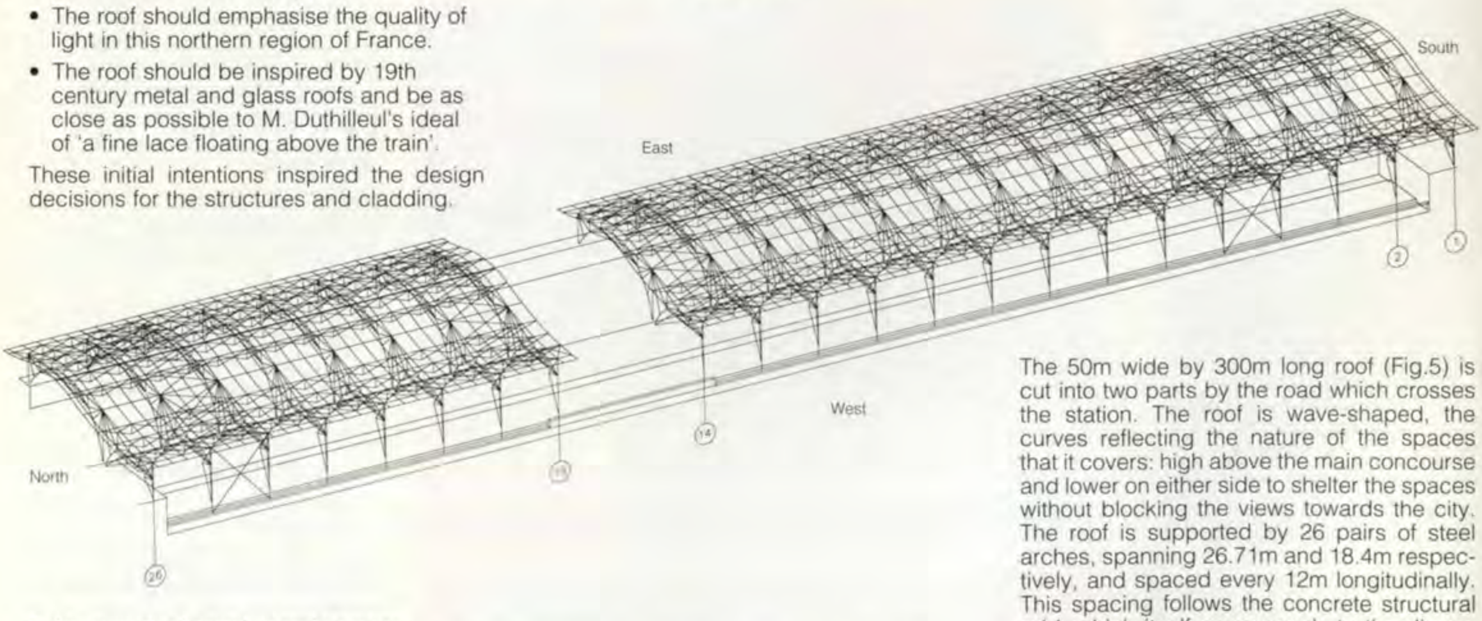
Structural description

The concrete station beneath the roof was designed by the SNCF's own architects and engineers, and has three levels which align with the different ground levels around it (Fig.4). The highest, which is the main entrance, is at the height of the ground on the east side of the station and at the level of the roads serving the station. The main passenger concourse, with all the functions of the station (ticket hall, circulation, shops customs zone, etc.), is at the intermediate level, whilst the lower level, which matches the lower ground level of the piazza on the west side of the station, has two platforms with two tracks each, and the tracks for non-stopping trains in the middle.

The arrangement of the tracks determined the geometry of the concrete structure, and the available lines of supports for the roof.

4. Transverse section.





5. Axonometric of complete roof structure.
The Le Corbusier Viaduct divides the building into two unequal parts between grid lines 14 and 19.

The 50m wide by 300m long roof (Fig.5) is cut into two parts by the road which crosses the station. The roof is wave-shaped, the curves reflecting the nature of the spaces that it covers: high above the main concourse and lower on either side to shelter the spaces without blocking the views towards the city. The roof is supported by 26 pairs of steel arches, spanning 26.71m and 18.4m respectively, and spaced every 12m longitudinally. This spacing follows the concrete structural grid, which itself corresponds to the dimensions of the train carriages.

Fire engineering

Paula Beever

In common with many countries in Europe and elsewhere in the world, France does not require that structures which support a roof only be fire-resisting. In the Lille station structure, however, a rather special problem arose. In France there are particular regulations designed for the protection of high rise (IGH) buildings which also impose restrictions on structures nearby. In particular they should have two hours' fire resistance to prevent fire spread. The World Trade Centre and Credit Lyonnais towers which span the roof (Fig.10) fall under the IGH regulations, so the roof below the towers and the structure supporting it at these points had to have two hours' fire protection. As far as the steel structure was concerned this would have necessitated the application of some suitable cladding material.

One possibility which was considered was the provision of a separate structural system suspended from the tower to support the roof immediately below and on either side of the tower. However, this solution presented a number of potential difficulties in its implementation, not least of which were its impact on the architecture of the roof below the towers, and the cost involved.

A fire engineering approach was therefore sought. This sets out to identify what the regulations are seeking to achieve and to explore alternatives which would meet the required fire safety standards whilst satisfying the other constraints on the design. The alternative proposed was justified on the basis of technical evidence and calculations.

Behaviour of steel

Steel loses its strength as temperature increases and the consequences of this loss need to be studied to understand the stability of a building under fire conditions. The Règles FA 'methode de prévision par le calcul du comportement au feu des structures en acier'[1] gives an engineering calculation method for this. In the UK, equivalent documents would be *BS5950: Part 8*[2] and its associated handbook. The Règles FA give the critical temperature Tcr at which failure of steel members would occur as a function of the applied stress. The Règles also determine the loads which have to be taken into account for fire studies.

To assess the fire behaviour of the structure of the station, a study was undertaken in collaboration with the fire laboratory of the CSTB in Marne La Vallée. This study fell into three principal steps:

(1) Development of design fires

(2) Analysis of effect of fires on individual steel elements to determine which members fail

(3) Analysis of the structure under the fire load case assuming failed members as calculated in (2).

Two possible types of fire were identified which could, in principle, seriously affect the steel. The first was a locomotive fire scenario, developed by CSTB, in which motor oil is assumed to burn. On either of the Quai Londres platforms it would be possible for flames to engulf steel members which form the arch.

The adjacent column would also be affected by radiated heat. The arch members engulfed in flame will become extremely hot and will fail. Therefore for the purposes of the structural analysis on the stability of the roof, it is assumed that the arch fails and carries no load. The analysis concentrates on the behaviour of the columns.

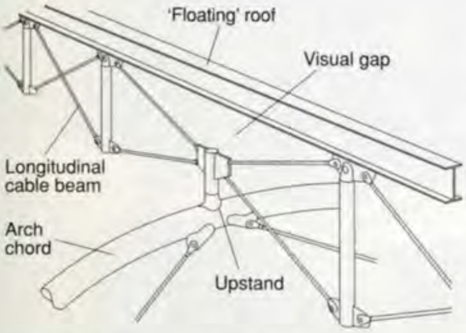
The second fire considered was one in a passenger carriage. This is assumed to be fully involved in fire, with the windows broken and the roof intact.

Flames could emerge and engulf the adjacent edge columns for a period of 30 minutes. The analysis showed that the columns would reach temperatures above the critical temperature for the load which they carried. In the case of the locomotive fire the columns as designed would fail. In order to ensure that the columns can survive the design fires it was necessary to propose some fire protection measures. Fire protection cladding was considered undesirable for architectural reasons, so the alternative was to increase the thickness of the steel in the column.

This makes the column stronger and reduces the applied stress. It also increases the critical temperature at which the column fails, and allows it to heat up more slowly so that it may not reach the critical temperature over the duration of the fire.

Accordingly, where the additional protection was needed the column wall thicknesses were increased by 5-10mm. In this way the standards required were achieved, in that the structure would survive the fire but without compromising the architectural uniformity of the column lines (Fig.7).

7. View along the Quai Londres, with the support structure for the Credit Lyonnais on the left. The station structure beneath is strengthened to survive a fire but without introducing cladding which compromises the architectural unity of the column lines.



6. Interaction between transverse and longitudinal structures.

To aid the impression that the roof is floating, the number of connections between the roof and the arches is kept to a minimum. The arches are made from slender tubes which are stiffened in their planes by an arrangement of ties. The arches support longitudinal roof beams that are also stiffened, out-of-plane, by an arrangement of crossed ties (Fig.6). The connections between the arches and the roof beams are not made in the plane of the arches, but on either side of them, via the crossed ties, which also enhances the 'floating roof' appearance. Longitudinal stability is provided by zones of cross-bracing in the roof and pairs of cross-ties between columns. Across the building, stability is provided by the arches and their non-prestressed ties, the latter also preventing buckling of the arches in their own plane. Out of their plane, the arches are restrained against buckling by the elements that connect them to the roof, and by fixity at their feet. Member end connections were made using steel castings welded onto the ends of the elements, high strength steels being used for the rods to keep dimensions as small as possible. Since the ties are not prestressed, they can only carry tension, which means that the structure is non-linear. The analyses of the structure were carried out using Fablon, Arups' in-house program, to check element stresses, stability and deflections. Also, a wind tunnel study was carried out by the Building Research Establishment in England and was used in certain cases to reduce the code forces.

Roof cladding

The choice of roofing system had to contribute to the 'floating' feeling as well as provide natural lighting to the station concourse. Penetration of light is achieved by the incorporation of thin strips of glass following the transverse curve (Fig.8), supported by curved steel troughs which are in turn carried by the longitudinal beams. Expanded metal panels are placed above the troughs to give a smooth, curved surface, with the troughs themselves clad with rockwool to provide sound insulation. No thermal insulation was required. Below this complex skin, a layer of perforated aluminium panels completes the system. The amount of perforations also varies across the cross-section to enhance the feeling of the curve.

8. Elevation of east façade, with inside of roof clearly visible.

9. End glazing exterior where the Le Corbusier Viaduct divides the station: The gap between the tops of the façades and roof structure is clearly visible.

Façades

The façades, in comparison, are simpler. They are all open at the top and do not touch the roof (Fig.9). Three different structural systems were used, one cantilevering from the ground with vierendeel trusses, one on a horizontal torsion member which is attached to the columns of the main structure, and the last as a structurally stiff plane pinned at the bottom and supported at the top by the roof beams. The cladding is made of glazing panels of about 1.6m x 2.4m and supported on their vertical sides only by aluminium extrusions.

10. Below: The Credit Lyonnais (left) and World Trade Centre (right) straddling the TGV station.

Conclusion

Although the total construction of the station took seven months longer than originally planned, it was opened, in May 1994, well in time for the arrival of the first Eurostar trains at the end of 1994.

The construction budget had been set at about FFr90M (£10.7M) at the end of the design development phase. The contractor's bid price was FFr76M (£9M), and the final price has remained within budget.

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(2) BRITISH STANDARDS INSTITUTION. *BS5950: Part 8: 1990.* Structural use of steelwork in building. Part. 8. Code of practice for fire-resistant design. BSI, 1990.

Credits

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SNCF Région Nord

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SNCF APG (M. Duthilleul)

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Steelwork contractor:
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Roofing contractor:
Laubeus SA

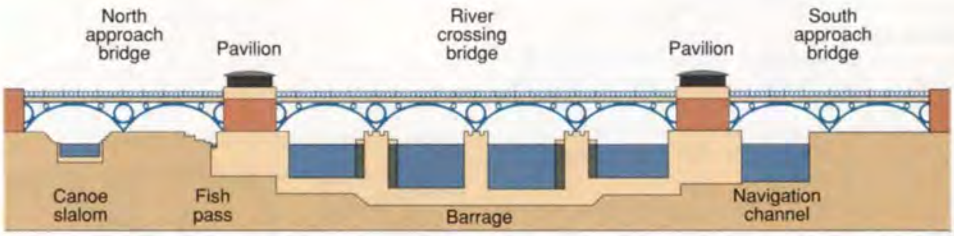
Illustrations:
1, 11: NAI
2, 4, 6: Trevor Slydel
3: Mary Evans Picture Library.
5: Derek Woodcraft. 7: Photo Poteau
8: Sophie Le Bourva
9, 10: Peter Mackinven

11. Interior of the station looking down on the main concourse.

The Tees Barrage Bridge

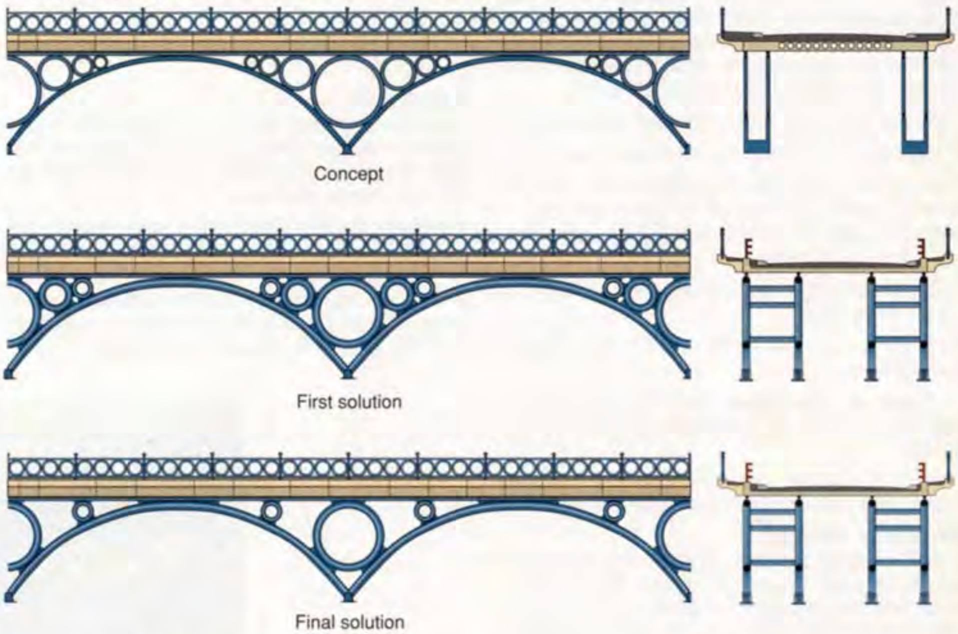
Neil Carstairs
David Stevens

1. Architect's competition model.



2. General arrangement of bridges.

3. Design development.



Introduction

In September 1987, the then Prime Minister, Margaret Thatcher, took a 'walk in the wilderness' at a derelict engineering works in Stockton-on-Tees in the north of England. She promised government assistance to develop the 100ha site, and it later became one of the 11 flagship sites of Teesside Development Corporation (TDC).

The River Tees is tidal here, and TDC decided that a key element should be a barrage, so that the unsightly mudflats exposed at low tide would always be covered. In late 1990 the Napper Collerton Partnership won a competition organised by TDC for the architecture of the barrage, the centrepiece of which was an elevated tubular steel arch bridge. Ove Arup & Partners subsequently won the fee competition for its engineering design organized by Montgomery Watson Ltd., the main consultants, who subsequently appointed Arups as sub-consultant for this element of the work.

Architectural concept

The architects' concept incorporated four main principles:

• To create a structure to signal the area's regeneration, celebrating the importance of the barrage and the crossing. The bridge would be an event both in itself and as seen from adjacent bridges.

• To build it in structural steel, to reflect the great Teesside tradition embodied in the local Transporter and Newport Bridges.

• To make a dynamic visual contrast between the massiveness of the concrete barrage piers and the airy filigree tracing of the bridge. Using such a principle it would complement rather than dominate nearby recreational uses of the restored landscape.

• To carry the steel motif across the adjacent navigation channel, access roads, fish pass, and canoe slalom, until natural ground level is reached.

It was concluded that a simple structural concept, drawing on the examples of early ironmasters, would best achieve the architectural principles, with each span a series of tubular steel arches, supporting circular infill members. The other main components of the competition entry were masonry-clad pavilions at each end of the river crossing, and a tower of lights on the central pier announcing and celebrating the entrance to the Teesdale site.

Scheme design

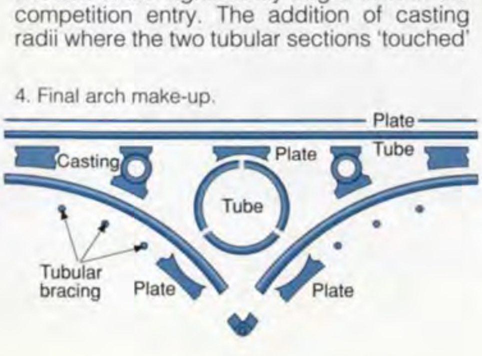
The main bridge has four 17.5m spans. At each end the road crosses the roof of the barrage pavilion and then an approach bridge with two identical 17.5m spans. The bridge is 160m long overall and carries a single carriageway road. The arches rise 5m to clear the navigation channel and service roads (Figs.1 & 2).

This concept had to become a structure meeting highway loading requirements. TDC specified that the bridge should carry the highest standard loading specified by the Department of Transport so that future industrial development would not be restricted by its capacity. This was some 10 times the design load of the customary use, in roofing, of such unusual tubular structures. The road which crosses the barrage links the once-derelict site into the local road network.

Arches and infills

The first task was to determine the structure's behaviour and the fabrication method. Cold bending of tubes to the radius required for the infills was impractical, as was forming a structural connection between two tubes ideally touching at a single point with a common tangent. A cast steel solution was thus developed, with the nodes cast separately and joined with tube-to-tube butt welds. A simple computer model showed, however, that both the arch ribs and the circular infill members needed to be significantly larger than in the competition entry. The addition of casting radii where the two tubular sections 'touched' gave a long length of connection, and the tubular appearance of the smaller tube was lost over this length. A constructive dialogue between the engineer, who knew what was possible, and the architect, who knew what he wanted, led to the circles being separated at the joints, and a flat 'plate' section introduced between them to form the connection. The number of infills was reduced and a clear space left between them, to maintain the structure's 'transparency' (Fig. 3).

4. Final arch make-up.



Articulation

At the piers the tubular arch members are joined together and pinned to the supports using purpose-made knuckle leaf bearings. The form of the steelwork, with no vertical element at the piers, meant that the bridge had to be made continuous with no movement joints, which also reduced the risk of water containing road salts leaking on to the structure. Combining fixed supports and continuous deck meant that a change in the bridge's temperature, normally accommodated by sliding bearings or bending of slender columns, would cause significant stress.

Arch spacing
The architect had a pair of closely spaced arches at each side, which put all the load onto the inner arch. To minimise member sizes the four arches had to share the load. Introducing bearings between deck and arches was considered, but the number required would have been expensive and would have led to future maintenance difficulties. Instead the pairs of arches were separated to give spans for the concrete deck of 2.75m and 3.6m, which allowed the transverse steelwork supporting it to be omitted. Horizontal bracing members were used between the pairs of arches rather than cross-bracing. A decorative parapet, echoing the circular motif, was supported on shaped precast cantilevers, but since this would not meet vehicle containment standards, a separate standard parapet was provided beside the highway.

Buildability
Introducing flat plates at the joints allowed a change from the all-cast solution. The main arch ribs would be circular hollow sections bent to the required radius, with the horizontal deck support and bracing as straight circular hollow sections.

The infill sections would each be cast with a solid circular cross-section, either with the plates integral with the casting or butt-welded on later - significantly cheaper than the all-cast solution.

After further refinements on cost grounds, the final solution, using the most economic solution found by the contractors that preserved the tubular appearance, was to fabricate the bridge from the following components:

- Straight tubes for the top boom and bracing
- Cold bent tubes for the main arch members
- Induction bent tubes for the larger infills (In this process successive short sections of tube are heated to red heat by an induction coil, bent and quenched.)
- Solid castings for the smaller infills with attached plates
- Castings for the lower half of the knuckle leaf bearings
- Plates for the upper half of the bearings and the remaining connections between the tubes.

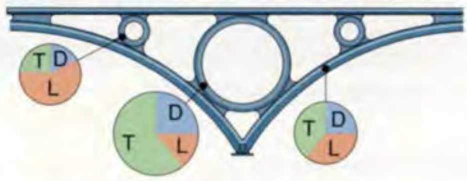
The final design contains 360T of tubular steel, and 280T of plates and cast steel.

Detailed design
Initial analysis showed that the bridge steelwork behaved unusually. In the final design, over half the thrust in the arch at the support was transmitted through the infill members into the deck at midspan. The proportion of vehicle load carried by a single arch depended on the position of the axles on the span. To quantify these effects, a space frame model of the whole bridge was developed.

Computer analysis
A few years ago a model sufficiently complex to represent this bridge could only have been analysed on a main frame, and even that would have given no insight into the structure's behaviour. Today the power of desktop computers and their programs make such analysis possible, and crucially, the results may be displayed graphically. The curved parts of the bridge were modelled by short straight elements, with additional moments included in the design check to compensate for this inaccuracy. At the nodes the plates were modelled by triangulated trusses for rigidity (Fig.5).

5. Basis of computer model.

6. Make-up of critical member stresses.



T = Temperature D = Dead L = Live

Loadcases
Live loading on a highway bridge is dominated by moving heavy vehicles, so load effects are normally determined from influence lines for the critical elements.

However for this structure it was impossible to predict which elements would be critical for sizing members under a combination of axial load and bending. 31 loadcases were analysed to represent the vehicle crossing half the bridge in regular increments.

Nine combinations of temperature and support settlement were combined with each of these, giving a total of 279 loadcases to be enveloped by the program. Even after design completion, when loadcases which gave stresses within 10% of the governing stresses were examined, it was not possible to justify reducing the number of loadcases or to identify a small number of critical members.

While the computer can indicate the most critical loadcase and element from the thousands of possibilities, the designer still has to be confident that the behaviour of the model will match that of the structure. Since hand calculations for such a complex model were impractical, a close study was made of the force and bending moment diagrams and, above all, the deflected form of the model under the critical loadcases.

Design stresses
In the initial analysis, live load effects dominated and member sizes had to be increased. After this the effects of changes in bridge temperature became more significant.

Further member size increases were counterproductive because an increase in stiffness in one member increased the stresses in all the others. It was therefore decided, once its availability was assured, that grade 55 steel should be used for the rolled tubular members. This gave an increase in capacity without a corresponding increase in stiffness.

Fig.6 shows the proportion of dead, live and temperature loads contributing to the critical stress in the different elements. A non-linear buckling analysis was used to determine the effective length of the arch members; this gave a small reduction in limiting compressive stress below the yield stress of the steel.

Concrete deck design
Design of the reinforced concrete deck is conventional. The heavy longitudinal bars, acting compositely with the steelwork, have to be provided over the full length of the deck, not just the supports. The contractor decided to use conventional rather than permanent formwork to avoid having to thread these bars through projecting steelwork.

8. Concrete barrage piers.

7. Below, the completed bridge in its industrial setting.

Corrosion protection

The exposed steelwork is protected by a sprayed metal coating and 250µm of acrylated rubber-based paint. Regular inspection and maintenance will give the best protection, rather than applying a special coating and then ignoring the bridge for a long time. The fully welded construction seals the tubular member voids against water ingress, and thus gives protection.

Specification

The DoT's Specification for Highway Works was used for all the bridges in the project, but it is not sufficiently flexible to cover all the works needed for this unusual bridge. Arups have used cast steel members as key structural elements in a number of buildings in the last few years, and the specification developed for these projects was incorporated in the contract documents. The standard specification's requirements for weld testing are written for the fabrication of plate girders (requirements for destructive testing of run-off plates from flange butt welds are not appropriate to the barrage). Again a specification developed for roof structures in buildings was adopted and incorporated in the contract documents. Requirements for materials normally relate to the as-rolled material, but there was concern that the heat treatment and quenching inherent in the induction bending process would affect the toughness of the steel. Further destructive and non destructive testing of the bent tube was therefore specified.It was necessary to limit the stresses due to changes in temperature to which the bridge will be subjected during its life. The site welds which establish the continuity of the structure had to be made when the air temperature (and so the temperature of the steelwork remote from the welding operation) was between 5 and 15°C.

Fabrication and erection

The combination of tubes, solid castings and thick plates in such unusual shapes was a challenge for the fabricator. 24 end (half arch) and 20 internal (double half arch) frames were produced over about six months. Full penetration butt welds on tubes

10. Casting in progress.

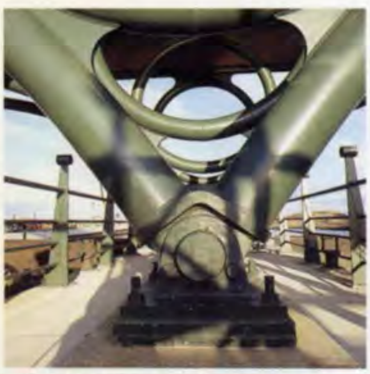
11. Casting condition survey.

12. Induction bending in progress.

13. Arch erection.

14. Inserting arch pin.

15. The bridge under construction: early 1994.



9. Detail of pinned arch supports.

up to 50mm thick were required, and welding activity dominated fabrication, taking 35 000 hours in all. Grade 50 and grade 55EE rolled steel were used, and A4 (modified) cast steel which gave equivalent properties to grade 50. The induction bent tube needed further heat treatment after testing to ensure adequate toughness. The metal-inert gas (MIG) process was used for all welds, with an electrode containing 2.5% nickel. Extensive preheat and controlled cooling was required throughout. 100% non-destructive testing (NDT) on butt welds and 40% on fillet welds, carried out 48 hours after welding, was specified. In addition immediate post-weld NDT by the fabricator allowed early identification of defects. The weld procedures used meant that the defect rate was very low. The prefabricated arch frames were brought to site as special loads on purpose-adapted trailers, and erected by 70-310T mobile cranes standing on the bed of the diverted river, with proprietary trestling at mid-span giving temporary support. After the line and level of the arches had been checked the main butt welds in up to 25mm thick tube were made. These had to be in a specific sequence and subject to ambient temperature restriction, which meant some night welding. Manual metal arc (MMA) techniques were used for all site welds and the fabricator had a welding technician on site throughout. Fillet welding of the cross-bracing between arches generally followed the main butt welding. The full paint system was applied to all site-welded areas, including shot blasting, metal spraying, and spray application of topcoats. Throughout fabrication and erection, a high level of planning, supervision and quality control was provided.

Barrage pavilions

At each end of the barrage there is a two-storey pavilion building. The south pavilion houses the control equipment for the barrage and navigation lock, the hydraulic power packs for the barrage gates, and the offices of the staff operating the barrage. The north pavilion, which contains a plant room for the barrage, is predominately for public use with a restaurant, a rooftop belvedere from which to view the barrage and river, and a basement with a viewing window to the fish pass. The road over the barrage is carried by the roof of the pavilion. The reinforced concrete roof slab in this area is 600mm thick and supported on four sides by reinforced concrete walls. The limits on allowable openings in these walls were a significant constraint on the planning of the layout of the pavilions.

Elsewhere the pavilion structure consists of 250mm thick slabs supported on reinforced concrete beams and columns. The pavilions are supported by an extension of the barrage raft foundation. The concrete structure is concealed by masonry cladding which contrasts with the exposed concrete of the barrage piers, while emphasising the solidity of the pavilion against the light steelwork of the bridge. Precast concrete units, matching the road bridge cantilevers, provide a visual link between the approach bridges and the main river crossing.

Bridge foundations

The barrage piers support the river bridge, pavilions, and the ends of the approach bridges. The remaining foundations for the approach bridgès are buried pad footings. On the north side one footing had to extend underneath the concrete channel of the canoe slalom, and the channel was strengthened to span across the footing when it settled. On the south side the two footings had to be tied together by a pair of buried concrete beams to prevent overturning of the base adjacent to the navigation channel. This base was founded 9m below finished ground level, on the base of the channel formed for the river diversion, and contained voids to reduce the soil bearing pressure to an acceptable level. The south abutment was conventional, but at the north abutment the road crossed another building's roof, formed from a 250mm thick slab spanning transversely onto 1m deep longitudinal beams.

Barrage footbridges, lifting bridge, and tower of lights

Pedestrians and cyclists are at river bank level, so a low level route across the four river spans and the navigation channel was needed. The former are four identical 14m long simply-supported footbridges, of twin universal beams with a steel plate deck. The deck cantilevers outside the beams, supported by shaped transverse plates at 1.75m centres. The gap between the beams forms a service duct for hydraulic and electric power to the internal barrage piers housing the gate mechanism. 6m long access manholes in the footbridge decks allow replacement of hydraulic pipework. The navigation channel is crossed by a steel lifting bridge which can be raised by a single hydraulic jack to an angle of 80°. Two plate girders support a steel trough deck which can carry vehicles up to 7.5T to service the south pavilion on the island between the navigation channel and the barrage. Parapets for these bridges match the decorative handrails on the main road bridges.

The tower of lights is a single tubular steel mast, tapering from 350mm to 610mm diameter, 29m high, stabilised by guys formed from Macalloy bars up to 34mm diameter. The mast and guys support reflective globes and plates, while the light source is at the tower base for maintenance access.

Conclusion

Designing the River Tees Barrage Bridge was a fascinating challenge, and its construction taxed the contractor's ingenuity. Without modern computers, the design would have been much more difficult. Whilst not the cheapest solution to the problem of crossing the barrage, it will give the Teesside Development Corporation a distinctive centrepiece for their flagship project.

Reference

(1) Department of Transport. Design Manual for Roads and Bridges. HMSO, 1992.

Acknowledgments

John Franklin, Tarmac Construction
Keith Temple, Westbury Tubular Structures

Credits

Client :
Teesside Development Corporation

Design/build contractor:
Tarmac Construction (Civil Engineering Division)

Main consultant:
Montgomery Watson (UK) Ltd

Sub-consultant and bridge designer:
Ove Arup and Partners Martin Butterworth, Simon Cardwell, Neil Carstairs, Graham Gedge, Andrew Kirton, Stuart Hunter, Nick Merridew, Ian Miller, Paul Morley, Chris Murgatroyd, John Read, David Stevens

Sub-consultant and architect:
The Napper Collerton Partnership

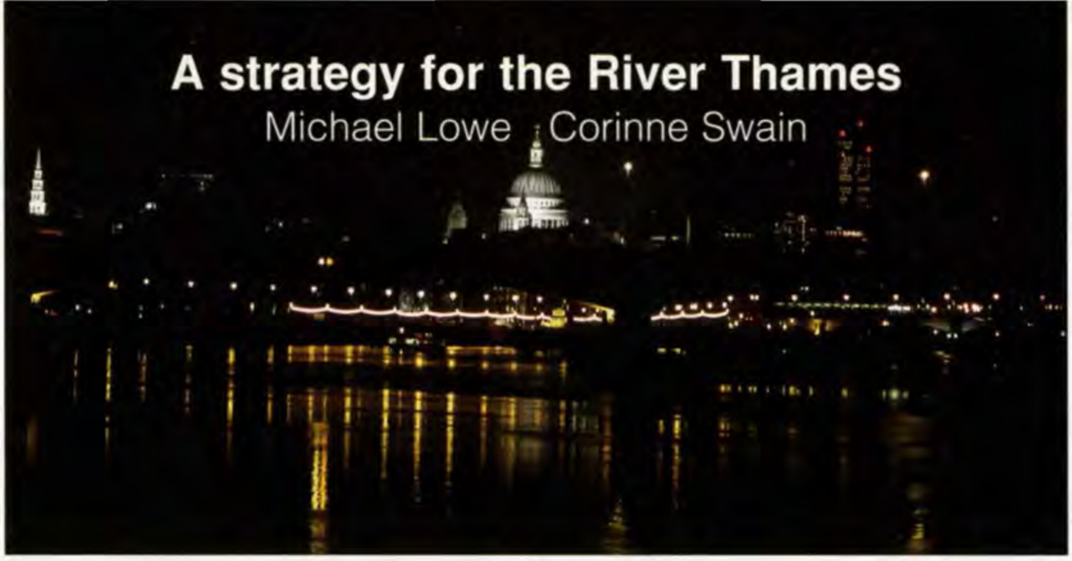
Sub-contractor for bridge structure:
Westbury Tubular Structures

Illustrations:
1: The Napper Collerton Partnership
2-6: Sean McDermott
7: Alan Proudlock (Photography) Ltd.
8, 9, 16: Bob Tyson
10-15: Cleveland Colour Labs

16. Barrage footbridge.

A strategy for the River Thames

Michael Lowe Corinne Swain



1.

Introduction

The River Thames is one of London's major assets. It has played a vital role in the capital's history and is an important visitor attraction. Yet to many it is an underused resource, and is often perceived as a barrier and a psychological dividing line between North and South London.

In June 1994, the Secretary of State for the Environment announced that he would be launching a study of the Thames between Hampton Court Palace and the Royal Naval College at Greenwich. 'A visionary document is needed... promoting a high quality of design and landscape along the River', he said. The study invitation attracted 76 teams, subsequently reduced to eight for the proposal and interview stage.

Arups was one of the few firms able to offer the full range of planning and design skills, and was commissioned by the Government Office for London in August 1994 to undertake a detailed analysis of the River, prepare overall design principles, and make recommendations for draft planning guidance. An intensive four-month period lay ahead for a team that incorporated skills in town planning, urban design, landscape architecture, transport planning, economics and tourism.

The aims of the strategy were to:

- raise public awareness
- enhance environmental quality
- protect areas of historic importance
- promote high quality design of new buildings and landscape
- safeguard river-related employment generating uses
- improve access to the River.

The study was to be strategic in nature, providing an overview of opportunities arising within the 50km stretch, rather than considering the development potential of particular sites.

Background analysis

During data gathering, the Arup team consulted many organisations interested in the Thames, via discussion groups, meetings, and events. Fieldwork was largely undertaken from boat trips.

These background investigations examined:

- the history of development along the Thames
- the evolution of decision-making bodies
- the river management regime
- the planning policy context.

Information was also assembled in map form on:

- distribution of riverside land uses and development opportunities
- accessibility along the banks and from the River's hinterland, and traffic use of the Thames itself
- areas of heritage and ecological importance along its length
- key landmarks visible from it
- building heights, urban form and landscape structure of different character areas along it.

A continuous photographic survey was also undertaken to provide a complete record, in 1500 images, of riverside development and environment conditions. This presented severe logistical problems to the Arup photographer in terms of access, glare, and how to display 100km of river bank, but these were overcome with perseverance.

The study's conclusions were produced in two parts:

- a design strategy (the creative elements)
- draft strategic planning guidance (the procedural output).

2.
Design guidelines showing recommendations on urban fabric, relationship to river, and building scale and massing.

The design strategy

The main elements are shown in Fig 3 overleaf. These are:

- identifying focal points to act as magnets for activity and transport interchange
- improving the quality of urban design and architecture
- creating a robust landscape strategy
- improving cross-river pedestrian access
- encouraging general environmental improvements.

Focal points of activity

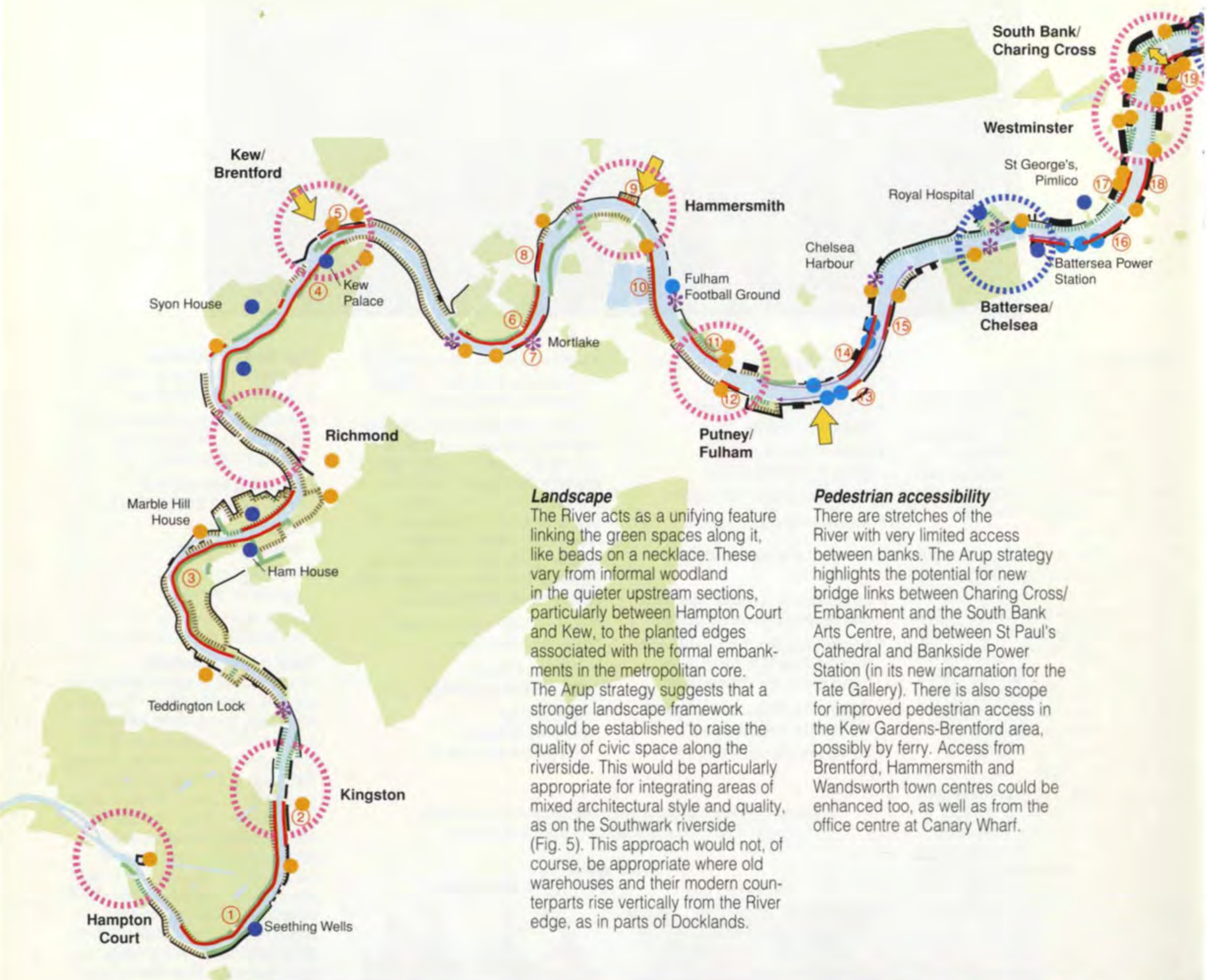
14 key centres of tourist and leisure activities were identified. These generally have good public transport facilities, often including a pier for river services and a bridge crossing. Richmond is an example of an existing focal point, where the open space in front of the development and the boating activities create a strong sense of place; whilst at Canary Wharf, for example, a major new focus of riverside activity could be created, linked to the water-based recreational opportunities at Limehouse Basin. The strategy suggests that there should be a series of places with which people can associate, perhaps identified with some form of marker or structure - akin to a River 'bus stop' - the design of which could be the subject of an architectural competition.

Urban form

It is crucial that both new development and the existing townscape do justice to their riverside location. Some development in the past has turned its back on the River or blocked public access to the riverside. To illustrate practical approaches, the Arup strategy includes a series of design guidelines (Fig.2), illustrating the importance of:

- permeability of new development to maintain circulation and visual contact with the River
- building forms that reinforce the River edge
- buildings in scale with the River and in context with surrounding development
- avoidance of disruptive building silhouettes.

3. The Arup Strategy Plan.



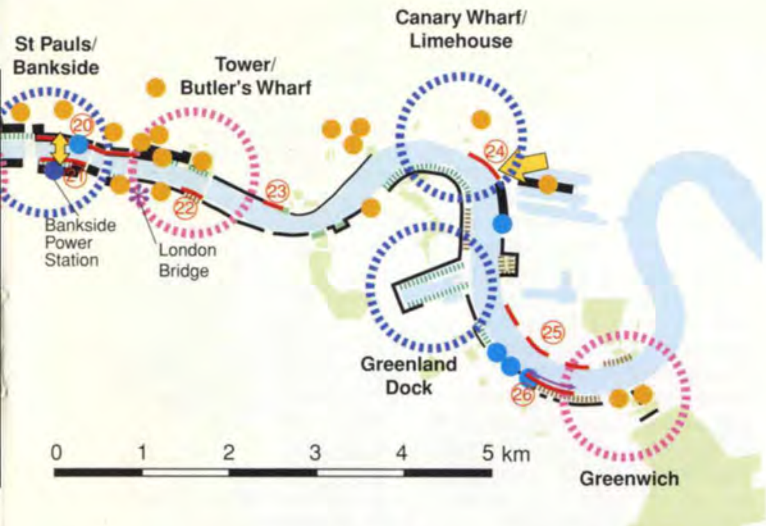
Landscape

The River acts as a unifying feature linking the green spaces along it, like beads on a necklace. These vary from informal woodland in the quieter upstream sections, particularly between Hampton Court and Kew, to the planted edges associated with the formal embankments in the metropolitan core. The Arup strategy suggests that a stronger landscape framework should be established to raise the quality of civic space along the riverside. This would be particularly appropriate for integrating areas of mixed architectural style and quality, as on the Southwark riverside (Fig. 5). This approach would not, of course, be appropriate where old warehouses and their modern counterparts rise vertically from the River edge, as in parts of Docklands.

Pedestrian accessibility

There are stretches of the River with very limited access between banks. The Arup strategy highlights the potential for new bridge links between Charing Cross/ Embankment and the South Bank Arts Centre, and between St Paul's Cathedral and Bankside Power Station (in its new incarnation for the Tate Gallery). There is also scope for improved pedestrian access in the Kew Gardens-Brentford area, possibly by ferry. Access from Brentford, Hammersmith and Wandsworth town centres could be enhanced too, as well as from the office centre at Canary Wharf.

4\.
Creating a vibrant riverside, particularly at the focal points of activity.



Enhancement Opportunities

1. Hampton Court Park
2. South of Kingston Road Bridge
3. Ham Lands
4. Kew Gardens
5. Brentford
6. Duke's Meadow
7. Mortlake
8. Corney Reach
9. Hammersmith
10. Barn Elms
11. Fulham Palace Gardens
12. East side Putney Bridge
13. Gargoyle Wharf Site
14. Fulham
15. Wandsworth
16. Nine Elms
17. Tate Gallery
18. Albert Embankment
19. South Bank Centre
20. St Paul's frontage
21. Bankside
22. West side Tower Bridge
23. Wapping
24. Millwall
26. Deptford Creek

General environmental improvements

A range of improvements are suggested as an integral part of future opportunities to enhance the River. These include a proposal to develop a corporate signage system for the Thames, selective use of public art and sculpture in scale with the River, and co-ordinated street furniture.

Also recommended is the preparation of a lighting strategy for the urban stretches of the River.
A sense of drama can be achieved with good accenting of historical landmarks, and festoon lighting defining the River edge, as at Victoria Embankment (Fig.1).

More could be done to enliven the riverside including illuminating and painting some bridges, and to improve security on parts of the riverside walk.

Planning guidance

The second part of Arups' recommendations covered ideas for draft strategic planning guidance for the Thames - not only the main study area, but also the downstream stretches from Greenwich to the sea. This guidance produced was complementary to the Thames Gateway Planning Framework produced by the Government in 1994.

Strategic planning guidance for the Thames will be a new form of advice to local authorities in preparing development plans and determining planning applications, and this study is the first time consultants have been used to draft such strategic or regional guidance.

The focus for it is to improve the consistency of the policy framework for the Thames, a problem that stems from having 13 local authorities with a river frontage between Hampton Court and Greenwich. In all cases, except Richmond which controls part of both banks, the River acts as a divide.

5.
A strong treeline would provide greater coherence to buildings along the Southwark riverside.

6.
Western Riverside, Wandsworth: a modern, well-designed waste transfer station including an elevated section of riverside walkway.

Several policy topics were analysed including:

- mismatch of boundaries on protective designations such as Areas of Nature Conservation Importance
- different ways of signifying the special character of the riverside
- need for inter-borough liaison in protecting key River-related views
- use of development briefs to encourage mixed uses and high design standards.

Two examples of planning policies are:

• *Thames path*
All the local authorities have given unanimous support to the creation of a continuous pedestrian route along both banks of this section of the Thames. Planning authorities have actively sought ways to provide new stretches of riverside walkway as planning gain when granting planning permission on new development.

At the time of the study there were only four significant missing gaps in the Thames Path, and the Countryside Commission is actively seeking to negotiate new corridors of access here.

Innovative engineering solutions are possible in some locations, as where Arups are currently assisting the Southwark Environmental Trust to provide a section of path in the Central London stretch. There is also potential for increased cycle use along the River. In some places, for example, it is possible for a separate cycle path to be provided inland of the riverside walkway. It is encouraging that since the study was completed, the Department of Transport has supported the London Boroughs' proposals for a Thames cycle route in the Transport Policies and Programme (TPP) settlement for 1995/96.

• *Protecting river infrastructure*
This is an area where planning policy needs strengthening.

Retention of wharves is critical to keeping open the option of supplying building materials to London by river, as well as taking away waste products, and at the time of study only 15 working wharves remained in this stretch.

The Arup strategy recommends that a system of safeguarding is included in planning policy around all remaining wharves, and that any proposal involving the loss of essential river infrastructure becomes a departure from the development plan.

Essential infrastructure should also include piers, landing stages and boatyards. The latter are crucial for maintaining tourist boats as well as freight, but have been under threat, particularly in the upstream sections. The strategy also recommends planning protection for smaller elements of river heritage, for example the steps and stairs that can be lost through new development. It suggests that planning authorities should consider adding such features to a local list. Some of these ideas have also already been included in revised strategic planning guidance for London, issued for consultation by the Government in March 1995.

A separate document containing draft strategic planning guidance for the Thames will be published by the Government Office for London later this year and will be subject to a formal period of consultation.

Thames Advisory Group

The Secretary of State for the Environment has appointed an advisory group of leading architects, journalists, developers and environmentalists to take forward some of the initiatives included in the Arup strategy. The Arup team made a presentation to its first meeting, chaired by John Gummer with two other Ministers, in early March 1995, and the Thames Strategy was formally launched by the Secretary of State in May. It will, it is hoped, provide the context within which imaginative ideas and practical proposals will come forward.

Credits

Client:
Government Office for London

Planning and Design Team:
Ove Arup Partnership
Lorna Andrews, Adrian Gurney, Corinne Swain (planning), Michael Lowe, Graeme Smart (urban design), Tom Armour, Claire Matthews (landscape architecture), Bernadette Baughan, Hugh Collis (transport), Jeroen Weimar, Paul Whitehouse (economics and tourism), Sir Jack Zunz (engineering and design adviser), Jon Carver (graphics), Peter Mackinven (photographer), Jo Scott (secretarial).

Illustrations:
1, 5: Michael Lowe
2: Michael Lowe/Tom Armour
3: Jon Carver
4, 7: London Rivers Association
6: Corinne Swain

7. Well-used riverside spaces with strong landscape at Coin Street and the Royal National Theatre on the South Bank.

The Western Harbour Crossing, Hong Kong

Eric Poon
David Snowball

1. Harbour road crossings.

Introduction

Anyone who knows Hong Kong will be aware of the problems of traffic congestion, particularly if they have tried to cross the Harbour at peak times of day. The Cross-Harbour Tunnel was opened in 1972 and now carries over 120 000 vehicles a day, which makes it one of the busiest tunnels in the world. A second one was opened to the east in 1989, as part of a major infrastructure scheme aimed at alleviating cross-harbour congestion. This now carries some 90 000 vehicles per day and already the approaches are blocked at peak times.

Almost as soon as the Eastern Harbour Tunnel opened, the Hong Kong Government commissioned a feasibility study for a third crossing, to the west (Fig.1). This would not only relieve pressure on the other two, but also act as a strategic link to the NW New Territories and China, via the Shenzhen-Guangzhou Superhighway, as well as to the new Chek Lap Kok Airport further west. Invitations to tender to finance, construct, and operate the Western Harbour Crossing on the basis of a 30-year franchise were issued in February 1992 for return the following July. The Western Harbour Tunnel Company was successful in its bid and an agreement was eventually signed with the Hong Kong Government on 2 September 1993. However, such is the pace of things in Hong Kong that work had already started a month earlier! The total cost is HK$7.5bn (including financing) and construction is planned to be complete by 30 June 1997.

Outline of the project

The Western Harbour Crossing is one of 10 Airport Core Programme projects defined in the 'Memorandum of Understanding' between the UK and Chinese Governments dealing with the establishment and funding of the new Airport (Fig.2).These include Chek Lap Kok itself and the MTRC Airport Express line (in both of which Arups have extended involvement in various roles), as well as the 1377m-span two-level Tsing Ma suspension bridge, part of the Lantau Fixed Crossing. The Western Harbour Crossing is, however, the only one of the 10 to be privately funded and therefore has not been subject to the recent uncertainties surrounding the Government-sponsored projects.

It consists of three principal elements: the tunnel underneath Victoria Harbour; the approach roads at Sai Ying Pun on Hong Kong Island, which include a grade separated interchange with Route 7 (the major trunk road connecting the Central Business District with the west of the Island); and the toll plaza on the West Kowloon Reclamation (Fig.3). The landfall in Kowloon is part of a major redevelopment, not only to accommodate the new highway and railway infrastructure but also for housing, commercial premises and public recreation - and all on land that did not exist three years ago.

2. Overall Airport Core Programme.

3. Site plan.

The franchise concept

The Build-Operate-Transfer (BOT) franchise concept is well known in Hong Kong, as it had been used in an embryonic form for the original Cross-Harbour Tunnel, nearly 25 years ago. More recent examples include the Eastern Harbour Crossing, Tate's Cairn Tunnel, and Route 3 Country Park section (where Arups are involved). BOT projects have gained favour in many parts of the world, notable cases in the UK being the Channel Tunnel and the Dartford Bridge. The principle is that the franchisee offers to finance, build and operate the facility for a set term during which he levies charges to users to secure a reasonable return on his investment and borrowings. At the end of the franchise period the facility is handed to the Government in good working order. The concept is an attractive one to Government as there is no investment of public money. In addition the franchisee assumes all the responsibilities for procuring the project, and has a single interface with Government. Major infrastructure projects such as highways, tunnels and bridges lend themselves to this approach as it is comparatively easy to prove their 'fundability' to prospective lenders, and to collect revenue by way of tolls.

The preparation of a franchise bid is a complex matter and there is not space here to deal with more than the key principles. The starting point is the project brief put together by Government as the basis for inviting bids. This explains Government's general requirements in respect of the project and the franchisee's organisation, and sets out detail design, construction, operation, and maintenance requirements.

No single organisation would normally have either the capacity or experience to bid for or undertake a franchise project alone. The usual arrangement, followed on the Western Harbour Crossing, is a joint venture to spread the risk between sponsor companies (shareholders), who amongst them must have experience of operating such a facility. Responsibility for design and construction is given to a major contractor or a joint venture of several companies. The contractor(s) are sometimes members of the sponsoring group, although this is not the case with the Western Harbour Crossing. The contractor(s) in turn employ design consultants. It will be usual for a group of banks and financial institutions to share the risk of providing capital.

The shareholders of the Western Harbour Tunnel Co. Ltd. are China International Trust & Investment Corporation, the principal overseas investment arm of the Government of the Peoples' Republic of China; Wharf Holdings, Kerry Holdings, and China Merchants. These companies have major interests in both China and Hong Kong in property, infrastructure and energy projects, shipping and transportation. Expertise on tunnel operations is provided by the Cross-Harbour Tunnel Co., a subsidiary of Wharf. The Western Harbour Tunnel Co. has let a contract for design and construction to a joint venture between Nishimatsu and Kumagai Gumi (NKJV).

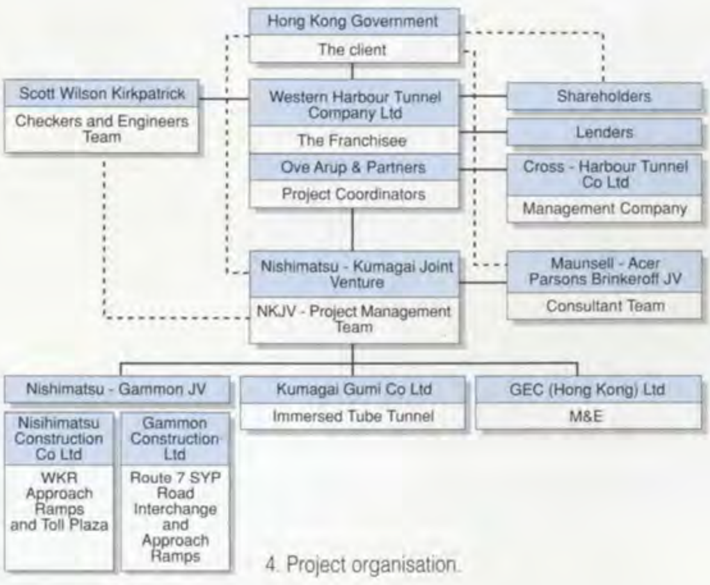
Project management

The Project Agreement between Government and Company makes the latter entirely responsible for delivery of the project on time to a standard acceptable to Government, and for subsequent operation during the remainder of the 30-year franchise period. The agreement allows Government to nominate two Directors to the Company Board, and approve all designs by delegated authority to a representative of the Director of Highways.
The Company has delegated its obligations and authority for design and construction to the NKJV, retaining only certain legal and financial obligations to itself. The contract with NKJV, a lump sum fixed price, embodies the whole of the Project Agreement and precisely defines the delegated powers, thus putting NKJV effectively in the position of the franchisee in dealing with Government. As required by the Project Agreement the Company has appointed a consultant to check both the design and works construction and act as engineer under the contract with NKJV.

The contractor has been deliberately placed in a powerful position to get a complex job done on time with minimum confusion over authority and lines of communication. NKJV has an enviable recent track record: Nishimatsu were lead contractor and major shareholder for the Tate's Cairn bored tunnel in Hong Kong (opened in 1991), and Kumagai Gumi participated in the Sydney Harbour tunnel (opened in 1992) and Hong Kong's Eastern Harbour Crossing, both immersed tube tunnels. Kumagai is a major shareholder in the former and has a minority holding in the latter venture. But getting the job done sometimes leaves other objectives not completely fulfilled, and confusion of interests can arise where the contractor is also a shareholder in the group of sponsor companies. This is not the place to argue either for or against contractor participation in the equity, but suffice it to say that the experience of the Western Harbour Tunnel Co. shareholders suggested contractor participation should be avoided and the Company should appoint its own 'watchdog' to look after Shareholders' interests.

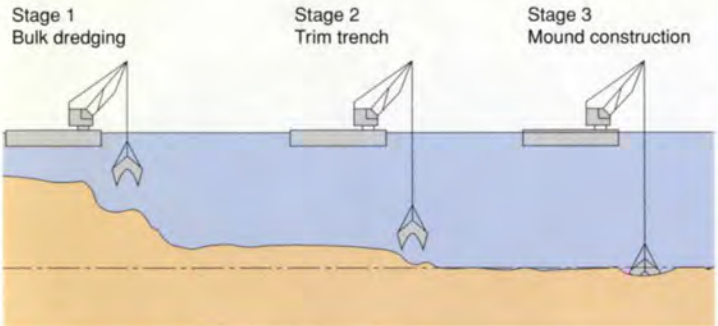
This led to the establishment of a Project Co-ordination Team and the selection of Ove Arup & Partners in September 1993. The position of the team within the overall structure is shown in Fig.4.

The role of the Project Co-ordinator is to represent the Company in technical and contractual matters, attend all principal project meetings with Government, the contractor, and the engineer/checker, to monitor and report on progress. Arups' role also includes liaison with the Company's Business Manager and the General Manager of the Cross Harbour Tunnel Co., to assist in the establishment of commercial, operating, maintenance and public relations policies and procedures. Perhaps the most interesting but sometimes frustrating part of the role has been to see that the Tunnel Company operations and maintenance requirements are adequately covered in the design. Whilst the Government brief for the project provided general requirements and standards, it could not possibly deal with the myriad details which might vex the operator. In an ideal world these would have been agreed with the contractor during the preparation of the franchise bid. In practice time was short and only the essentials were included (and priced for). This left the details to be hammered out during the approval and design development stages. The Tunnel Company tackled the problem by arranging for the General Manager of the Cross Harbour Tunnel Co. to work with Arups to define operational needs for the designers. Maintenance expertise was added to the team by the early recruitment of a Tunnel Engineering Manager. The incorporation of these detail needs has been made against the background of a lump sum construction contract where changes are usually difficult and expensive to make, but with goodwill on both sides many of the requirements have been met.

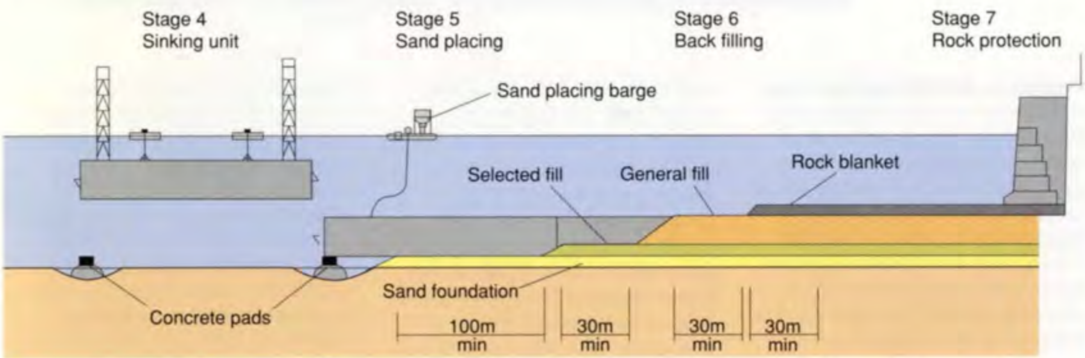


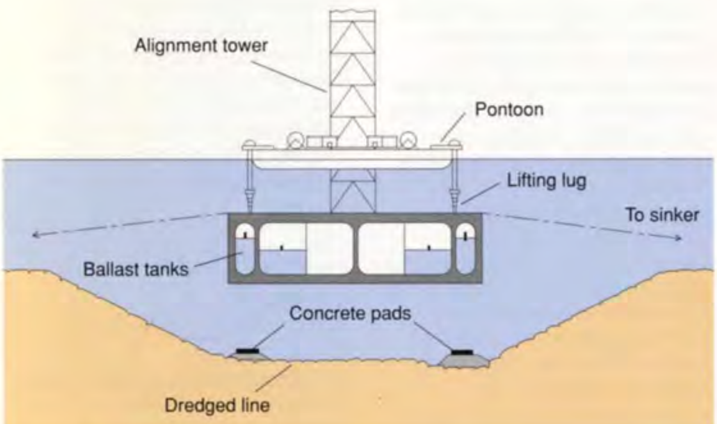
4. Project organisation.

5. Left: Casting basin: tunnel units batch 1 under construction June 1994.



6. Above and below: Tunnel construction sequence.





7.
Tunnel construction stage 4: cross-section.

The business of the Company is reviewed through a hierarchy of meetings. A relatively informal review of key issues is made each week by the Chairman, Managing Director, Business Manager and Project Co-ordinator; the Executive Committee of the Board meets each month to make a formal review of progress and receives reports from the engineer/checker, Business Manager and Project Co-ordinator; and the whole Board convenes each quarter, when both Business Manager and Project Co-ordinator make formal presentations of the financial and progress status of the project, highlighting critical issues.

All the Directors have many other interests and an unwritten rule has been adopted whereby no meeting lasts longer than one hour - a superb discipline to focus the mind on the really important matters!

Much of Arups' effort is directed towards monitoring progress and preparing reports. Although NKJV prepare a monthly report, the Company was concerned to make an independent assessment of project status. To this end Arups appointed a Programme Control Manager who had previously worked on the Sydney Harbour Tunnel, and so brought first hand knowledge of this type of project to the team.

The tunnel

The crossing is designed as a dual three-lane highway with an ultimate capacity of 180 000 vehicles a day, although the daily flow when it opens in 1997 is expected to be under half that. The tunnel is being constructed as a 1.3km long reinforced concrete immersed tube between ventilation shafts on either side of the harbour, with short cut-and-cover sections on the landward sides, bringing the overall length between portals to 2km. Longitudinal ventilation ducts are provided on both sides of the immersed tube section with cross-connections to the road tunnels; the cut-and-cover tunnels have overhead ventilation ducts.

The immersed tube consists of 12 units, each approximately 113m long x 33.5m wide x 8.5m high. They are being fabricated in three batches of four in a casting basin at Shek O on the south side of Hong Kong Island, excavated below the floor of a partially worked out quarry close to the sea (Fig.5). When each batch is complete the basin is flooded and the units towed to a temporary mooring for final fitting-out and thence to the harbour. The entrance channel to the casting basin is then closed with a floating caisson gate to allow the basin to be pumped out for fabrication of the second batch.

The units are sunk into a prepared trench dredged from the harbour bed (Figs.6 & 7), from which marine muds are removed and replaced with sand up to tunnel founding level to limit settlement. The logistics of the marine works are considerable, as it is necessary to make several diversions of the shipping fairway through the harbour to allow dredging and sinking of the units.

Planning is made more difficult by the need to co-ordinate the works with the Airport Railway tunnel, also an immersed tube, which runs close to the road tunnel. Moving the units is an impressive sight as each displaces 35 000 tonnes and requires four tugs to manoeuvre it.

The first batch left the casting basin in January 1995 and the first unit was sunk into position on 15 March 1995 (Fig.8). The ventilation shafts and cut-and-cover tunnels at each landfall are constructed by the top-down method using diaphragm walls, sunk to sound rock head.

8. Tunnel unit 1 being floated into position at ventilation shaft (Hong Kong side), 15 March 1995.

The shafts are major elements in themselves, being some 38m in diameter with road level 20m below ground and diaphragm wall cut-off approximately 40m lower. A 'docking bay' is constructed in cofferdam on the seaward side of each shaft to receive the immersed tube units. Each shaft will support a ventilation building to house the tunnel fans for providing fresh air or to exhaust smoke in the event of a fire and associated transformers and switchgear. At the time of writing both shafts are complete and the building superstructure on the Hong Kong side is under construction.

The approach roads

The highway works at Sai Ying Pun on Hong Kong Island stretch 2km from the end of the Rumsey Street Flyover to Belcher Bay, where land is still being reclaimed and will not be available to the contractor until mid-1995 (Fig.9).

This long thin site lies alongside Connaught Road West in a heavily populated residential area and poses the type of problems to the contractor which are typical of this kind of work. Complex traffic and utilities diversions are required to allow sections of the jig-saw to be pieced together, whilst keeping construction noise and dust to tolerable levels. The contractor's problems in constructing some 17 separate bridge structures, 15 of which are currently in hand, have been compounded by some rather patchy ground conditions. The land upon which much of the work is being done was reclaimed about 10 years ago and in places deep pockets of marine mud have been found, some 20m thick.

This has required deep barrette or bored piled foundations for the structures and a ground treatment programme where approach ramps are located. Treatment generally consists of installing 'wick' drains on a close pattern grid and surcharging the affected areas to accelerate settlement.

Toll plaza

Both the contractor and the Tunnel Company set up their principal offices on the West Kowloon Reclamation site, close to the toll plaza area, where work started in autumn 1994. This will accommodate 20 traffic lanes, some of which will be equipped with auto-toll equipment to allow subscribers to pass through without stopping - particularly advantageous to the bus companies. The Tunnel Company administration building will be constructed close to the toll plaza, and will house the control room where traffic flow, toll collection and tunnel environmental conditions are monitored, and from which action can be directed to deal with any emergencies. To the north of the toll plaza there is an interface with the Government Contract for the West Kowloon Expressway. Work has recently started on the Kowloon Station (Arup design) of the Airport Railway, which is immediately adjacent to the toll plaza.

9.
Part of model of grade-separated interchange between tunnel approaches and Route 7 (note tunnel portal in upper left of picture).

Progress monitoring by Arups

A review of contract documentation revealed that neither the construction contract requirements nor the contractor's monthly reporting would provide clear information on the progress of the works. Indeed the form of lump sum contract adopted meant the Tunnel Company had very little detailed information on the make-up of the contract sum.

There was thus a need to develop a system of progress monitoring, and to this end a model was developed with the following objectives:

- to provide a baseline programme for assessment of the progress of the project
- to track critical paths, hence allowing identification of likely problem areas and adverse trends
- To forecast the achievement of key dates, payment milestones and the final completion date
- To allow presentation of the results of monthly progress monitoring in concise, simple terms for the franchisee's monthly and quarterly reports.

Primavera Project Planner (P3), a project planning and control computer software, provides the basis of the progress monitoring model. The model was developed by summarising activity sequences in the contractor's works programme within each cost centre so that the logic links and date constraints were maintained. Each summary activity was coded by cost centre and geographical area for aggregation for reporting purposes.

To present progress concisely and simply in terms of percentage completion, it was necessary to assign weightings to the summary activities of the programme model. These were derived by assessment of major quantities or cost estimates and allocated as a resource value in Primavera. Cumulative curves of the weightings can be generated to provide the target progress curves for the project. The programme model contains about 550 summary activities with the maximum weighting allocated to any individual activity no more than 1% of the project total. Thereby errors in weighting assessment are limited.

The progress of each activity in the programme model is updated monthly as a percentage completion. Progress is assessed, whenever possible, by identifying the achievement of key events and measuring the actual amount of work done. Information on progress is also obtained from the monthly reports of the independent design and works checkers as well as the contractor. Monthly progress is compared with the target programme, and the results presented graphically on a summary bar chart and cumulative progress curves in the franchisee's monthly reports. As there are assumptions and judgements made in establishing the programme model and in assessing the monthly progress, the predictions of project completion are not intended to be absolute. It is more important to watch the progress trends than the monthly figures themselves.

In addition to the progress monitoring of the Western Harbour Crossing Project, monitoring of the progress of interfacing Government projects is also carried out to assess their effects on the opening of the tunnel.

The Project Agreement requires the Tunnel Company to make a monthly progress report to Government. This distills information from NKJV's report and includes the independent assessment of project status and a projection of the completion date. The Arup Team also issues a quarterly report for the Board, which is lavishly illustrated and produced to a high standard by Arups' Hong Kong Graphics Group. Last but by no means least a quarterly report is prepared to satisfy the lending Banks, which has to be certified by Arups as an accurate record of the project's status.

Involvement with a project of this nature and size, itself a part of the gigantic group of Airport Core Programme projects, is exciting enough. However, a fascinating aspect of Arups' role has been to take part in the variety of tasks involved in building a new company literally from scratch. Working with the Business Manager, the Arup team has devised a tailor-made document control system, assisted the development of public relations policy, are helping to recruit key operations and maintenance staff, are initiating proposals for auto-tolling and carriage of telecommunication links to enhance operating efficiency and revenue, and are briefing visiting groups from China and other Asian neighbours - to mention a few of the current tasks. Experience has shown that Arups has a lot to offer companies in a similar position. It is to be hoped that this will be the first of many such commissions.

Credits

Client:
Hong Kong Government

Franchisee:
Western Harbour Tunnel Co. Ltd.

Project Co-ordinator
Ove Arup & Partners Hong Kong Ltd.
Eric Poon, David Snowball
(permanent site team)

Daniel Leung, Sinny Lo, Pat O'Neil, Grant Robertson, Agnes So, Paul Suett, Andrew Wolstenholme, Damon Yuen (Hong Kong)

Allan Delves (London)

Advice and help on a variety of issues has been given by Frode Hansen (consultant to Arups in London), Ron Cookson, Stephen Lam, Wilkie Lam, and Tony Read.

Illustrations
1-4, 6,7: OAP Hong Kong Graphics Group/Trevor Slydel
5, 8, 9: Peter Yiu,
Western Harbour Tunnel Co. Ltd.

The Pavilion, Blackpool

Steve Burrows
Rick Houghton
Mike Robinson

1. Brickwork detail on the refurbishment.

Introduction

This exciting and unusual project involved partially demolishing a large steel and concrete-framed building, as well as major structural remodelling of the internal features and construction of a complete new façade to improve appearance and durability - and all while the ground floor retail units remained in occupation and trading.

Construction was completed in September 1994 and the refurbished building (Figs.1 & 8) is now fully occupied.

Major tenants include Top Rank who operate an 1800-seat bingo hall and Woolworths, who have used the project to renew their trading presence along the promenade of the most popular seaside resort in Europe.

History

Up to 1962 this prime island site next to Blackpool Tower was occupied by traditional seaside resort promenade buildings (Fig.2), including the Palace Theatre. Lewis's Ltd. bought and cleared the site to make way for their flagship store in the north west of England; the new five-storey building, completed in early 1964 (Fig.3), boasted air-conditioning, restaurant, cafeteria and hairdressing services - every aspect oozing modern boldness and optimism. For many years its appearance, with its green glazed honeycombed screen wall, divided opinions, but love or hate it, it is difficult to argue that the brash statement it made was not appropriate to the seafront character. In 1991, with the demise of Lewis's as a trading company, Grant Thornton were appointed receivers to oversee the sale of their assets, including the building and site at Blackpool.

2. The original buildings c.1960.

3. The famous postcard showing the new Lewis's store,shortly after completion in 1964.

Appointment route

Ove Arup & Partners Manchester were first appointed by Grant Thornton to report on the building's condition. The structural survey was mainly external and revealed extensive damage to many of the exposed elements: cracking and spalling of the concrete, the result of chloride contamination corroding the reinforcement and encased rolled steel sections. Following issue of the survey report to prospective purchasers, Arups were then appointed by the new owners, Chartwell Land, for the structural engineering design associated with their redevelopment proposals.

4. New two-storey void created at first floor level.

Proposal

Chartwell were very much driven by the current retailing strategy to limit upper floor trading. Basically, the building had too many floors, and with demand for office space limited and future demand at best uncertain, the most cost-effective solution was to remove the roof, fourth floor, and most of the third floor.

Not all the development was to be refurbished for retail use. Chartwell identified the possibility of offering some two-thirds of the first floor, 2400m², for leisure use. This space had to be flexible to attract as many potential tenants as possible, and this was addressed by providing a two-storey high void over half this area (Fig.4). Demolition also entailed removing a large area of second floor, so that a total of four levels of floor were removed in this area. Radical change to the external appearance was also fundamental to the brief, with emphasis on improved durability.

Out went 'modern' reinforced concrete and in came traditional brick masonry, ironically mimicking the style of the original buildings.

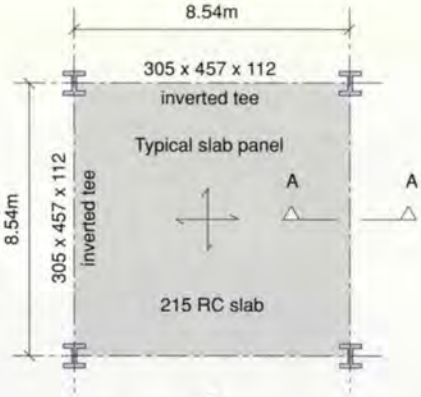
All this sounds quite straightforward - but work had to proceed while the ground floor tenants continued trading, a restriction applying to about two-thirds of the building footprint. This put severe restrictions on the works in relation to noise, dust, and use of the basement service area for construction materials handling and storage. A carefully planned sequence of protection, demolition, and reconstruction was essential to ensure tenants' and public comfort and safety.

The challenge on site

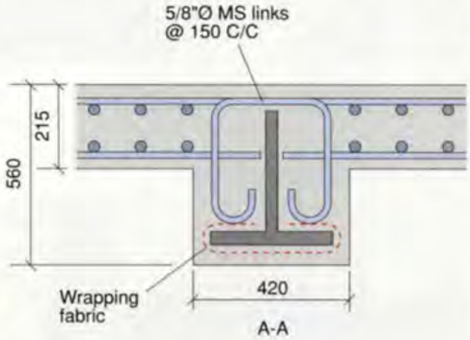
One of the first tasks was to learn as much as possible about the existing fabric and structure. Fortunately, prints of several original structural engineer's layout drawings and a selection of the architect's plans and sections were stored in the building.

These gave a good indication of the nature of the original construction but did not describe the many structural changes, particularly to the lower floors, since 1962.

A detailed internal structural and measured survey was essential, and to achieve the earliest start date for detailed design the client opted to commission the survey whilst Lewis's was still in operation.



5.
Typical construction of original composite floor beam, above: plan on typical bay and below: section A-A.



6.
Close-up of original inverted T-beam.

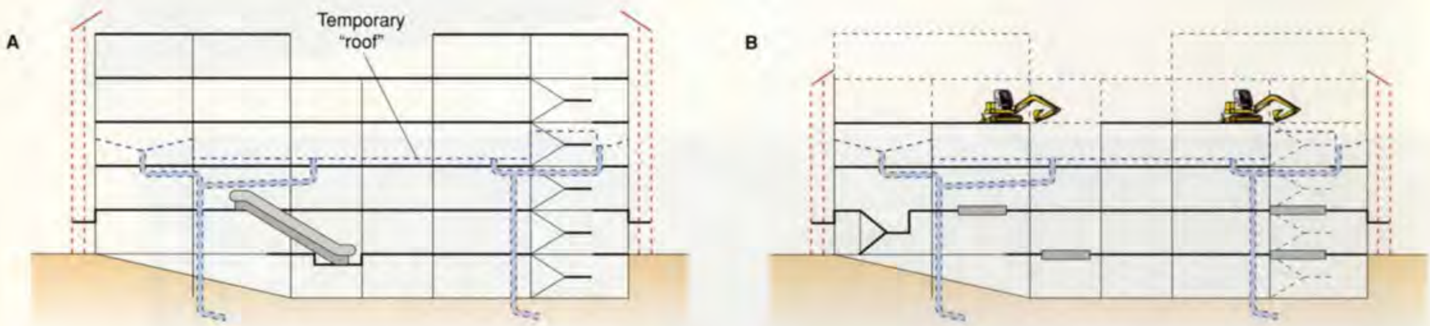
The measured survey had to be used with caution. Many of the dimensions related to column casings later found to be eccentric to the structural columns, due to rainwater pipes and ducting, and in some places access to the structure had been virtually impossible because of 30 or so years of accumulated merchandise, display units and general junk in stockrooms. Thus during the design it was decided to revise the building grid dimensions in line with the original steelwork setting-out.

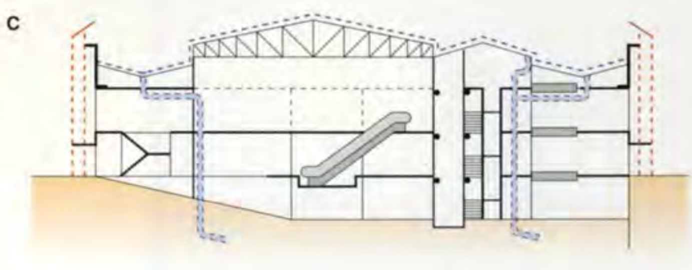
The fact that the original skeleton was a steel frame, fabricated and erected to relatively close tolerances, enabled much of the remodelling to be developed and drawn with confidence that details would work, prior to any investigations on site. As a result the design team was able to keep comfortably ahead of site progress, and significant changes were mainly avoided.

Existing structure

Though many fundamental structural aspects of the original design were deducible from the limited number of construction drawings, at this early stage several questions remained unanswered. Enquiries of the local building records department proved fruitless. However, the Institution of Civil Engineers provided an address in France for the original designer, now retired, Mr. I. Pilkington (MICE), who was contacted and proved most willing to assist.

Even after 30 years he remembered the design clearly, and gave a first-hand insight into how stability, durability, fire protection, and other technical issues had been solved. He was able to recall imposed floor loadings, later verified by back calculation from beam reactions indicated on steelwork layouts. One invaluable piece of information was the justification for the composite nature of the steel and concrete floor beams (Figs.5 & 6). Prior to his contribution, simple calculations had indicated that composite action was essential to the integrity of the floors. Modern composite design utilises welded shear studs to transfer the large tensile and compressive flange forces from steel to concrete. However, investigations on site, plus photographic records of the original works, showed no mechanical connection between





A 1 Install temporary waterproofing generally at second floor
2 Erect scaffold

B 1 Commence Phase I demolition works to upper floors
2 Begin internal remodelling, new stairs, escalators, etc

C 1 Erect roof steelwork and make watertight
2 Remodel perimeter concrete profiles to accomodate new masonry
3 Complete demolition works to create 2 storey void (Phase 2 demolition)
4 Complete internal modelling and reclad facades

7.
Sequence of refurbishment works.

8.
The 1995 refurbishment.

the steel beams and the concrete casings. Mr. Pilkington, who described himself as a 'pioneer in composite construction', loaned the original report on full-scale testing of a two-span beam specifically commissioned prior to the design of the store. Together with tests on site samples, the report confirmed the load-carrying adequacy of the floor beams.

Slabs were a little more straightforward. However, with span-to-effective depth ratios as high as 45:1, many panels did not comply with modern standards. This manifests itself, not unpredictably, as fairly large long-term self-weight and creep deflections, although these are difficult to detect without surveying equipment or conveniently placed puddles of rainwater! Long-term effects, however, had taken place and subject to the new load requirements the slabs were found to be adequate from basic principle analysis.

Remodelled building design

With the rest of the team, Arups developed a work sequence to minimise impact on the ground floor trading tenants and the public (Fig.7). To keep down costs and temporary works, the new roof at second floor level was designed to act as protection to the existing structure during demolition, and permanent protection to areas of second floor now converted to roofs. The mesh reinforced concrete screeds used performed so well that no significant repairs were needed prior to final asphalting and laying of insulation.

The intricate polychromatic brickwork proposed by the architect demanded a rationalised approach to ensuring its stability. Cold-formed stainless steel channel sections with horizontally-spanning cavity construction provided the most cost-effective design solution. Careful consideration of special brick shapes and bonding arrangements was required to ensure flexural continuity without resorting to excessive quantities of bed-joint reinforcement.

Internally the replanning determined that none of the existing staircases or lift shafts were suitable for reuse. These features were variously modified, including infill, partial infill, widening, and conversion from escalator or lift shaft to staircase. Many new openings were also created for the three new lifts, two new escalators, and 10 new staircases.

Extensive perimeter concrete works were also needed for the necessary profiles and support of the new masonry cladding. These included recasing steel columns affected by chloride contamination and corrosion, and providing upstand parapet walls and new support plinths at first floor level.

Although in situ reinforced concrete usually offers the most flexible material for structural modifications to existing structures, all the new staircase and lift shaft framing was designed using steel for maximum prefabrication and rapid progress on site. Concreting was generally limited to infilling openings and trimming new openings.

The works

Given the speculative nature of parts of the project and the usual unknowns of refurbishment, Chartwell opted for a management type contract.

The five main packages were temporary waterproofing, demolition, roof steelwork, concrete remodelling, and masonry cladding. It is a tribute to the careful planning and execution of the demolition that there were no serious injuries during the contract. Some 18 000T of material were broken up and removed.

Work began in early 1993 and was completed in time for 1994 Christmas trading. During the works, the management contractor had to deal not only with normal site issues, but also be comforter to the various tenants and their particular needs. Principally this involved informing them of works, progress, and effects on their property.

Conclusion

Such a challenging project exposes the engineer to many problems not usually encountered on a typical new building. Successful completion of the £5.3M Pavilion has given Blackpool promenade a refreshing facelift and a change of facilities for both locals and the many visitors. This change to the seafront will also boost the local postcard industry, as Britain's most popular holiday 'Wish You Were Here' demands a retake!.

Credits

Client:
Chartwell Land, Meon Projects

Architect:
Leach, Rhodes & Walker

Structural engineers:
Ove Arup & Partners Steve Burrows, Mark Green, Rick Houghton, Andrew Marsland, Mike Robinson, Graham Scull, Rob Silvester, George Suthers

Services engineers:
MEDA

Management contractor:
Tilbury Douglas

Illustrations:
1, 8: Peter Mackinven
2: Ove Arup & Partners
3: E.T.W. Dennis
4: Studio D Photography
5, 7: Trevor Slydel
6: Rick Houghton

St. Mary's Car Park, Sunderland

Ray Noble
Malcolm Shaw

Introduction

St Mary's Car Park, south of Sunderland's fine Wearmouth road and rail bridges, marks the entrance to the city centre. It represents a new concept in car park design, with paramount importance given to quality, safety and security for both people and their vehicles.

The emphasis is on user friendliness, imaginative and sensitive design with good vehicular and pedestrian access, and high standards of lighting, security and finishes.

As prime agents, Ove Arup & Partners were fully responsible for the complete design.

The project manager's role, and structural, civil, mechanical and electrical services design, were all undertaken in the Newcastle office. The Napper Collerton Partnership were architectural sub-consultants, and quantity surveying duties were shared by Arups and Bucknall Austin as sub-consultant.

Continued overleaf:

1. St. Mary's Car Park : a new concept in design both for vehicles and pedestrians. Secure, brightly lit and user friendly.

4. Aerial view: two metal-clad arched roofs span the parking areas, pedestrian bridge is in foreground.

2. Stone dressed brick work detail, metal security grilles to the lower floors can be seen at right.

Design criteria

In establishing the design criteria Arups were particularly concerned to avoid the problems and deficiencies of multi-storey car parks built since the 1970s; those in Sunderland city centre, for example, are greatly under-used due to vandalism, theft, fear of mugging, and poor vehicular access and circulation.

The aim was also to establish a high quality architectural style appropriate to the city's improving image. The architecture evolved as an expression of form and structure using traditional means of scale, proportion, detail and materials. Elevations are brick-clad with appropriate stone dressings, and articulated by the expressed 5m perimeter structural grid. Double-height openings with contrasting decorative brick spandrel panels establish a strong vertical scale. Metal grilles provide security to the lower two floors, while glazing to a new pedestrian bridge built over the ring road at second floor level, and to the curved curtain walling of the main staircase and lifts provides contrast with the robustness of the brick detailing. A metal-clad roof formed from two shallow curved arches, reflecting those of the Wearmouth Bridge, spans the main parking areas.

Structure

The structural arrangement is the key to the overall design, which incorporates clear-span, open-plan floors with uninterrupted views, improved circulation, and little concealment for thieves. Its basis is a series of in situ concrete frames at 16.5m centres, and minimal use of internal 500mm diameter columns. The external columns are on a 5m grid set in the line of the external walls. The in situ frames support a floor comprising 16.5m long precast concrete beams at 2.5m centres and precast concrete decking with in situ topping. Downstand beams are minimised. The joints between the in situ frame and precast elements are cast monolithically, extending the life of the building and reducing maintenance costs. The floors to the parking areas are laid to falls to facilitate drainage, with gullies cast into the floor slab/column junctions and discharging to downcomers located at column positions. A central in situ reinforced concrete ramp, 6.5m wide with a slope of 1:10, provides vehicular circulation between floors. Reinforced concrete shear walls at the corners of the building supply overall stability. The structural design was developed in conjunction with the building services and security requirements. The 2.5m structural grid was designed to coincide with parking bay widths, allowing integration with luminaires at regular intervals.

3. Pedestrians leave the car park by staircase or glazed lift to the footbridge.

5. Glazed pedestrian bridge over ring road at second floor level provides direct access to city centre shopping area.

6. Night view of the brightly lit car park. Wearmouth Bridge is seen left of picture.

Servicing, layout, and operation

Lighting levels have been carefully considered to create a bright, but glare-free, safe environment, with good vertical illuminance to ensure that facial features are well lit.

Lighting uniformity is achieved by eliminating dark corners and patch areas.

Vehicular circulation areas and parking bays are naturally ventilated through openings in the external façade. However, a roof-mounted mechanical extract system augments air quality to pedestrian circulation areas, lift lobby, and main staircase.

The layout incorporates control rooms at both the ground floor vehicle access and the pedestrian access to the footbridge. The ground floor control room houses monitoring equipment for the extensive CCTV monitoring system, which covers all entry and exit points, the car parking areas, the main stair and lift lobby, and the pedestrian access over the footbridge through Green Street Arcade to the city centre. Security is further enhanced as the two fire escape stairs to the north elevation have doors linked to an internal alarm system which operates in the case of misuse.

The user friendliness of pedestrian routes is improved by the incorporation of large glazed areas to the main staircase - designed to department store standard - and in the incorporation of two scenic lifts on the south elevation. This enables clear views both within the car park and to the outside, reducing criminal opportunity and increasing customer confidence in their safety.

Another integral factor in the scheme was consideration of access points for both vehicles and pedestrians. The users would be mainly shoppers relying on short-term visits of around two hours or less, and the total of 484 spaces, including 20 for disabled users, are arranged on four levels of parking. Internal dimensions are significantly above standard minimum requirements. Parking bays are 2.5 x 5m, with an aisle width of 6.5m to allow unimpeded parking. The headroom is generally 2.2m. Security reasons led to there being one point of entry and exit for vehicles at ground floor adjacent to the control room, with pedestrian access via the new footbridge over the inner city ring road. The link this forms between the car park and the shops marks an extension of the city centre pedestrian network. Access is again enhanced by the use of two glazed lifts serving street and bridge level, in addition to a staircase.

The designers recognise that design per se is only a starting point and that the quality of management is vital to its continued success. However, the adoption of vandal and graffiti-resistant finishes assists in the maintenance of this facility. The main staircase and lobbies being fully tiled and all exposed concrete painted with anti-carbonisation paint enhances future performance and maintenance. The City operates the car park with full-time security guards and a manager, and the well fitted-out ground floor control room, mess room, and money counting facility now form the control centre for the whole of Sunderland's car parking operations.

7. Parking bays: open plan floor provides uninterrupted views with minimal use of internal columns.

Conclusion

Site work began in October 1992 and the car park was operational by Christmas 1993. The total project cost was £5.4M, a high proportion of which was devoted to security, architectural, and maintenance considerations. The design is now seen as not only setting new standards for car parking in Sunderland but is accepted by the local authority as establishing levels of civic design in the city that others must emulate. The car park has now been in operation for 18 months, during which there has been no reported vandalism, assault, or thefts from vehicles or of vehicles themselves - a testament to the safety conscious design and client management of the facility. The convenient and efficient 'Pay-on-Foot' system* allows a current throughput of some 9500 cars per week; the high percentage of women users clearly indicates the success of the design philosophy.

***Pay-on-Foot system**

- Customers pay only for time used.
- Computerised logging and payment, hence maximum revenue.
- Valid ticket required on exit/entry via control barrier and rising kerb, hence enhanced security.
- Vehicle counting system incorporated.
- Financial audit data information provided.
- Operational security with minimal manpower.

Awards

- ***Gold Award***: National Secure Car Parks Scheme, sponsored by private industry and the Association of Chief Police Officers (1994)
- ***Robert Stephenson Award:*** Design and Concept Category, promoted by the Institution of Civil Engineers Northern Counties Association (1995)
- ***Regional Award:*** Norwich Union Safe Car Parks Scheme (1995).

Credits

Client:
Sunderland City Council

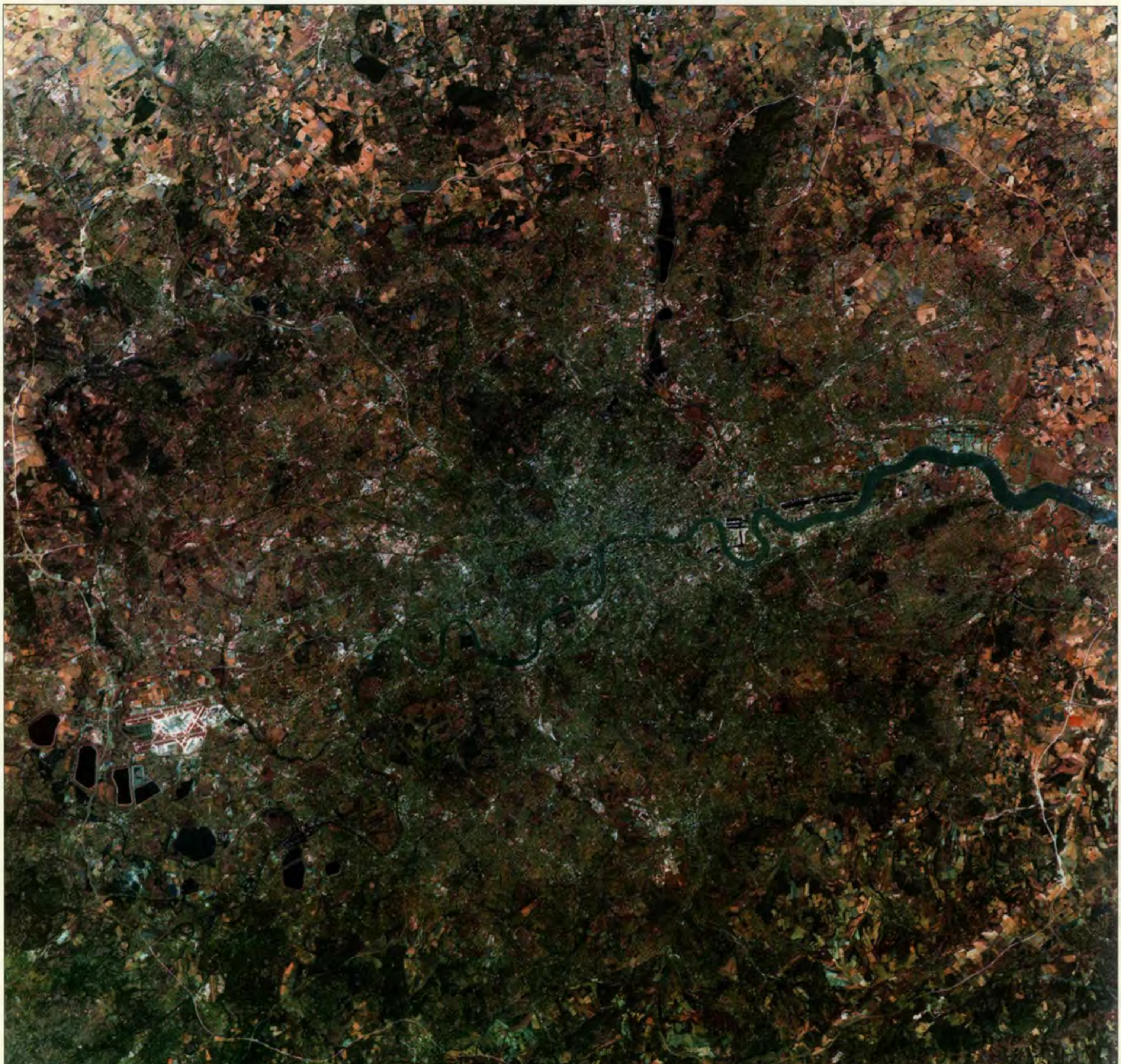
Project manager and consulting engineer:
Ove Arup and Partners Yasmeen Al-Boutie, Andrew Goodfellow, Jennifer Gunn, Nigel Harrison, David Hillcox, Nick Merridew, Garry Miller, Ray Noble, Steve Pearce, Colin Peart, Malcolm Shaw, Steve Shaw, Scott Wallace

Architectural sub-contractor:
The Napper Collerton Partnership

Quantity surveying sub-contractor:
Bucknall Austin

Main contractor:
Laing (North East) Ltd.

Illustrations:
1, 3, 5, 6: Sally Ann Norman
2: N.E. Studios
4: Harry Marsh Ltd.
7: Ian Bambrick



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