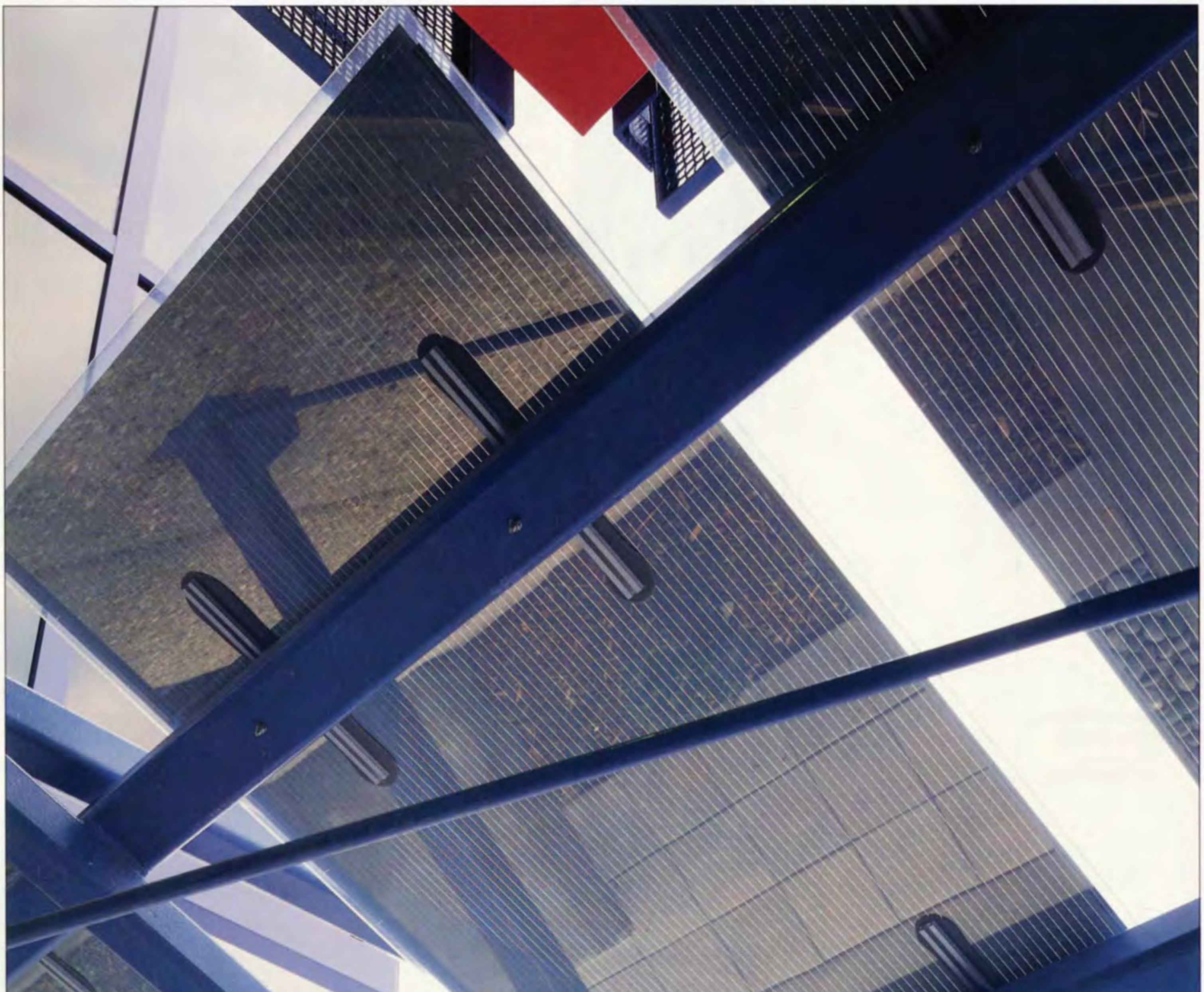
THE ARUP JOURNAL

4/1993



THE ARUP JOURNAL

Vol.28 No.4
4/1993

Editor:
David J. Brown

Published by
Ove Arup Partnership
13 Fitzroy Street,
London
W1P 6BQ

Art Editor:
Desmond Wyeth FCSD

Deputy Editor:
Hélène Murphy

Front cover:
Photovoltaic panels installed on the awning at the APS facility, Fairfield, California (Photo: Richard Barnes).

Back cover:
The setting sun illuminates the top of Central Plaza, across Victoria Harbour, Hong Kong (Photo: Colin Wade).

Planning high speed railways into Europe
Mark Bostock
Terry Hill

3

Following publication in March 1989 of British Rail's route for the Channel Tunnel Rail Link, Arups decided on their own initiative to examine radical alternatives, and announced their solution in March 1990. By October 1991, after much re-examination and consultation, the stated Government preference became a route 'on the lines put forward by Ove Arup'. The Partnership is now centrally involved in the planning and design of the final route for the Link.

The Western Morning News
Peter Bailey

8

The new state-of-the-art production building and administrative headquarters for this West of England newspaper company stands just outside the city of Plymouth. Ove Arup & Partners were responsible for designing the dual structure, a self-supporting reinforced concrete frame within a virtually free-standing steel and glass enclosure.

The APS project, Fairfield, California
Alisdair McGregor
Pam Brandon Ehart

12

Photovoltaic panels are an innovatory, environmentally-friendly power source for the 1990s, whose manufacture requires stringently-controlled conditions. Ove Arup & Partners California were structural and services engineers for Advanced Photovoltaic Systems' new production facility located in Fairfield, between San Francisco and Sacramento; the office areas of the building are themselves clad in PV glass panels.

Central Plaza, Hong Kong
Peter Ayres
John MacArthur

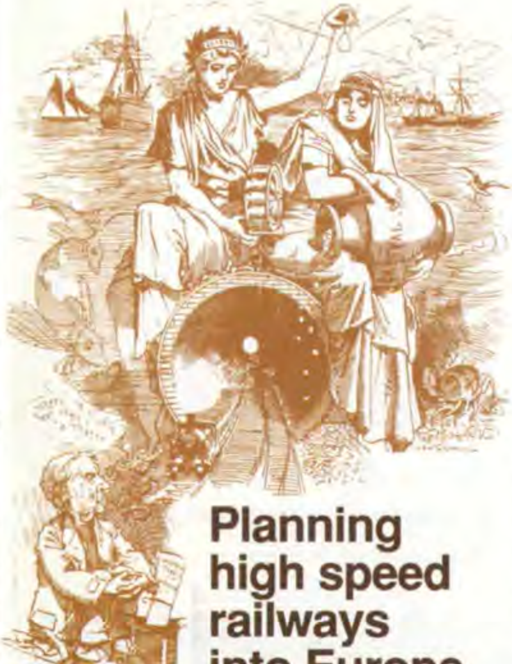
16

The world's tallest reinforced concrete building was completed in less than three years from acquisition of the site. Ove Arup & Partners Hong Kong designed the foundations and the superstructure, and were centrally involved in the building's extremely fast construction programme.

'Japan Bridge', Paris
Kate Purver
Pat Dallard

22

Ove Arup & Partners and Peter Rice's French practice, RFR, collaborated on the design of this 100m span, steel tied-arch footbridge over seven lanes of urban motorway at La Défense. Its shape recalls the curving profile of a traditional Japanese bridge.



Planning high speed railways into Europe

Mark Bostock   Terry Hill

Introduction

Interest in high speed railways in Europe is at a peak. The French *Trains à Grand Vitesse* (TGV) network is expanding and new lines are also being built for the German Inter City Express (ICE). In Britain a high speed link between London and the Channel Tunnel will, it is hoped, be agreed by early 1994. This railway is the most significant link in the rapidly developing European high speed rail network, which is establishing rail travel as a practical and high quality alternative to air and road. Arups have been actively involved in the route alignment for the Channel Tunnel Rail Link, now called the Union Railway (UR), and in its subsequent development. This article, with its parallel Chronology beginning opposite, highlights the various roles Arups have played over the period 1989-1993.

The need for a Channel Tunnel Rail Link: 1986-1990

There was no early acceptance of the need for new rail capacity through Kent when the Channel Tunnel was being planned, nor recognition that rail speeds on the UK section of the London-Paris/Brussels journey might be a deterrent to passengers. When the Channel Tunnel Bill was deposited in 1986, British Railways (BR) maintained that the existing network of lines and stations was, in the main, adequate for the foreseeable future. With hindsight, this can be seen as an odd conclusion, since journey times from the south-east to Central London are amongst the worst there are for routes of equivalent distance. Even without the Channel Tunnel, a case could perhaps have been made in this radial sector for a new high speed route to London to cut journey times by more than 40 minutes. However, in arguing this it is worth remembering that the Channel Tunnel was, and is being, privately promoted, so it was probably wise not to make its fortunes dependent, in part, on a major public sector project.

The 'Kent Impact Study' published by the Department of Transport (DTp) in August 1987, after the Channel Tunnel Act had been promulgated in the previous February, found that new rail capacity would be required if growth in rail traffic was not to be constrained. In 1988, BR published three possible routes through Kent, and two through South London, forming four different route combinations (detailed in Chronology opposite). The uncertainty amongst the public about the real impact of a new railway caused widespread property blight. By March 1989, a single route was chosen which was different in detail from any of the four 1988 routes. This exacerbated the uncertainty.

Government was keen that the private sector should be prime movers of the project and after a pre-qualification procedure in December 1988, BR invited six consortia (listed in Chronology overleaf) to bid. Arups were the lead member of one group, but the group that won was the Eurorail joint venture, comprising Trafalgar House and BICC.

Having seen the 1989 BR route — which was generating great opposition despite featuring much tunnelling through South London — Arups decided, on their own initiative, to examine radical alternatives. Through an extensive and intensive round of consultation, they developed an approach that was not just a route, but also a strategic concept embracing route, environment, development, and regeneration. It was also clear to Government, BR and Arups that domestic as well as international services were going to be a vital element of the project. In March 1990 Arups published their own route proposals (analyzed on pp.4-5). These followed existing transport corridors, passed through derelict and landfill sites, avoided built-up areas, and entered London on an easterly approach via Stratford. Following publication, it was clear they would gain widespread support.

Meanwhile, the winning Eurorail team re-examined BR's route — the so-called Southerly Approach — and came up with some amendments aimed at improving performance and profitability. These involved less tunnelling than the 1989 route and made greater use of existing rail corridors through South London. Despite these improvements, however, considerable public expenditure was required to make the project attractive to private sector financing. For this reason Government found the proposals unacceptable. In June 1990 the then Secretary of State for Transport asked BR, amongst other things, to re-examine all routes between the North Downs and London, including those via Stratford.

The selection of the Eastern Approach: 1990-1993

Several alternatives to the BR/Eurorail Joint Venture proposal were being promoted, but only one would be chosen. Mid-1990 to mid-1991 was a period of intense activity, in both technical evaluation and political lobbying. BR carried out a comparative study in which basically four routes, including their own Southerly Approach, were evaluated. Both BR's and Arups' routes headed towards Kings Cross with its unparalleled rail interchange, but Arups' route featured a Stratford interchange with two other important existing planned rail routes, the London CrossRail and the London Underground Jubilee Line extension. The two other proposals terminated at Stratford. To aid comparison, all the proposals which were further evaluated by BR were modified and assessed as twin-track passenger railways, having a 1:90 ruling gradient with similar service patterns.

To page 5 ▶

Chronology

October 1982 Nicholas Ridley appointed Secretary of State for Transport.

February 1986
The Channel Tunnel Treaty was signed by Margaret Thatcher and François Mitterand. Britain and France agreed to the private construction and operation of a tunnel rail link under the English Channel between Cheriton in Kent and Frethun in the Nord-Pas de Calais.

May 1986 John Moore appointed Secretary of State for Transport.

February 1987
The Channel Tunnel Act received Royal Assent. Waterloo was chosen as the first terminal for international passenger trains. It was recognized soon after the passing of the Act that the existing Kent railway system would be inadequate to cope with increased international passengers and freight demands resulting from the Channel Tunnel by the turn of the century.

June 1987 Paul Channon appointed Secretary of State for Transport.

July 1987
BR started a search to find the additional rail capacity needed to cope with Channel Tunnel traffic. This exercise included identifying a London terminal additional to Waterloo. BR looked at more than 100 sites for the second terminal — Kings Cross was chosen.

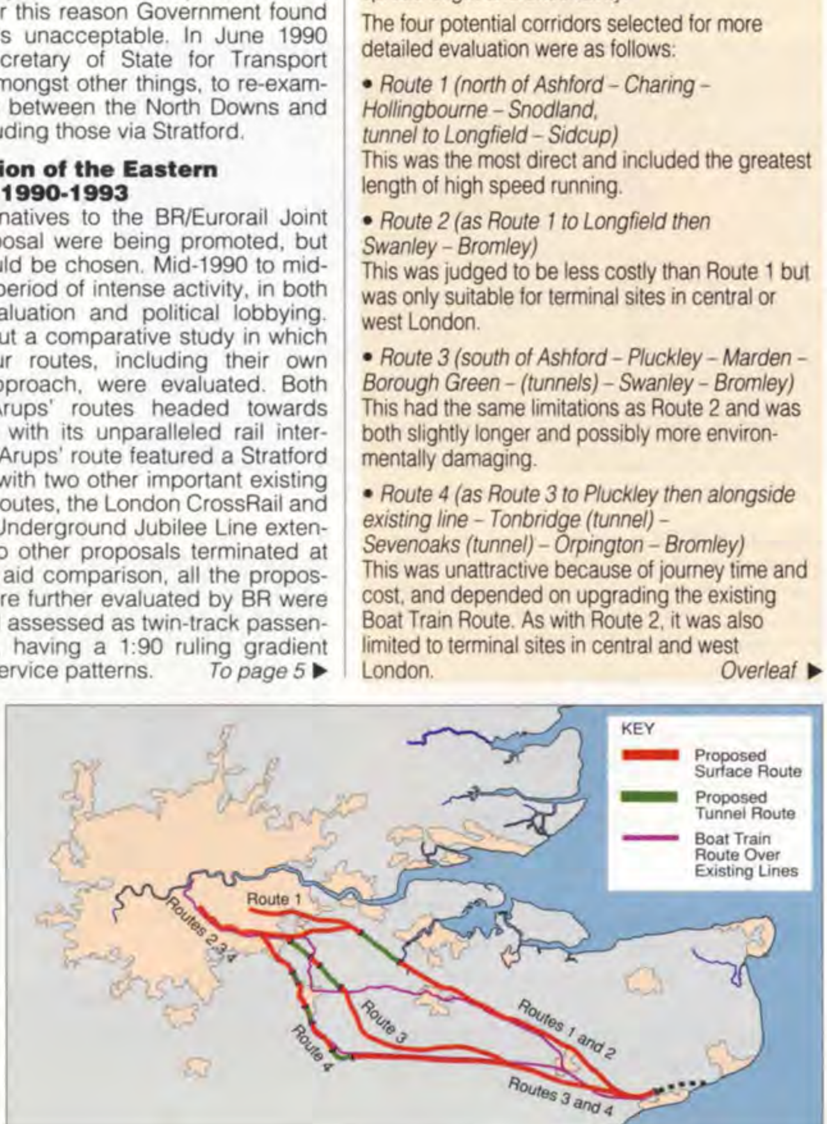
July 1988
BR's team submitted a report to the BR Board, identifying four routes through Kent (Fig. 2).

These were subsequently identified and announced publicly, resulting in alarm and opposition. The lack of understanding of and information on the real impact of the new railway caused widespread blight and uncertainty.

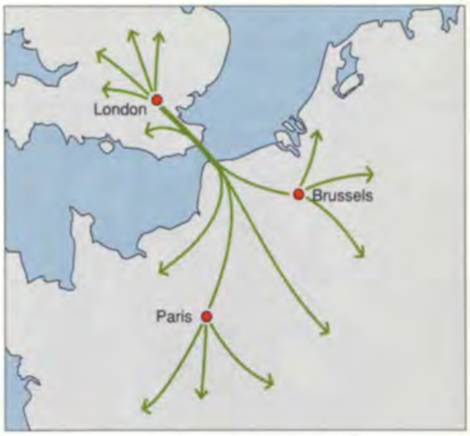
The four potential corridors selected for more detailed evaluation were as follows:

- *Route 1 (north of Ashford – Charing – Hollingbourne – Snodland, tunnel to Longfield – Sidcup)*
This was the most direct and included the greatest length of high speed running.
- *Route 2 (as Route 1 to Longfield then Swanley – Bromley)*
This was judged to be less costly than Route 1 but was only suitable for terminal sites in central or west London.
- *Route 3 (south of Ashford – Pluckley – Marden – Borough Green – (tunnels) – Swanley – Bromley)*
This had the same limitations as Route 2 and was both slightly longer and possibly more environmentally damaging.
- *Route 4 (as Route 3 to Pluckley then alongside existing line – Tonbridge (tunnel) – Sevenoaks (tunnel) – Orpington – Bromley)*
This was unattractive because of journey time and cost, and depended on upgrading the existing Boat Train Route. As with Route 2, it was also limited to terminal sites in central and west London.

Overleaf ▶

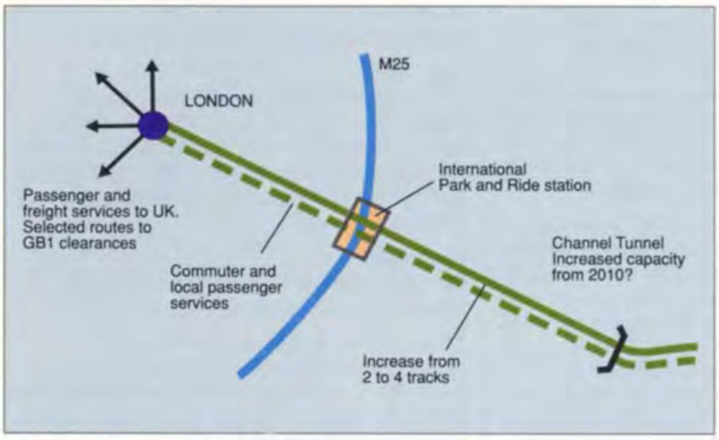


2. Routes identified by BR in July 1988.

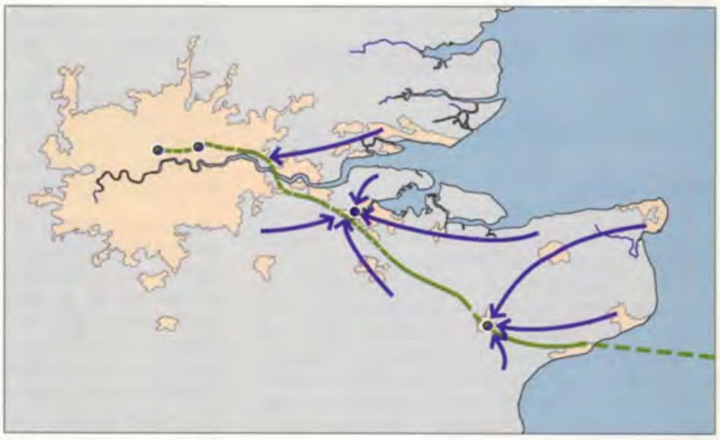


3. Left: Published BR Route, March 1989.

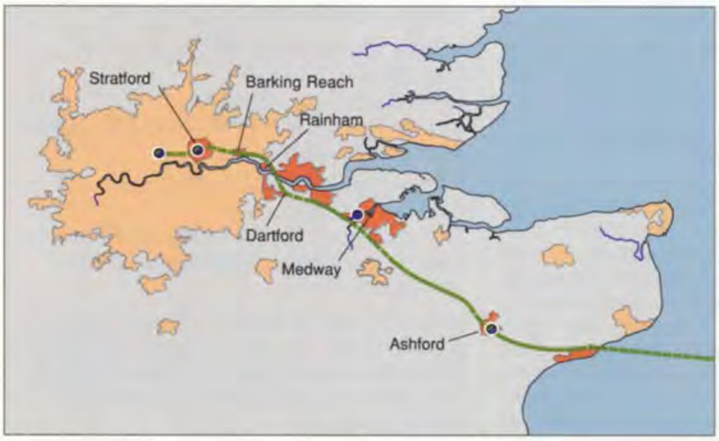
4-8. Implications of the Arup March 1990 proposals.
4. Above: Transport corridor linking the UK with Europe.



5. Capacity expansion possibilities.



6. Commuter services.



7. Opportunities for regeneration in the East Thames Corridor.

8. Environmental considerations.

December 1988
The Government made it clear to BR that the project could only proceed if the private sector were given the opportunity to participate. Six consortia were invited to tender, as follows:

- *Acer:* (Acer Consultants, P & O Group, BAA plc, Canadian Pacific, Hambros Bank)
- *Costain:* (Costain Group plc, Wimpey plc, Taylor Woodrow plc, Spie Batignolles SA, Credit Lyonnais, Sanwa Bank)
- *Davy/AMEC:* (Davy Corporation, AMEC plc)
- *Eurorail:* (Trafalgar House plc, BICC plc)
- *Kent Rail:* (Ove Arup and Partners, S G Warburg and Co Ltd, County Nat West, Wood Mackenzie and Co Ltd, Slaughter and May, Linklaters and Paines, Berwin Leighton, Sir Frank Layfield, Jones Lang Wootton)
- *Laing/Mowlem/GTM:* (John Laing Construction Ltd, John Mowlem and Co plc, GTM International SA)

By July 1989 bids had been received from five of the six. Davy/AMEC decided not to tender and, following submission, the Costain consortium withdrew. The bid with which Arups were involved was from a professional team. Given the importance being attached to private sector finance, the offer was to develop the project jointly with BR and to find the most appropriate route. The Kent Rail team proposed that this Joint Venture would form the basis of a strong management and owning company, on the basis of which the project could be properly specified and the necessary banking and construction contracts put out to tender. Eurorail was eventually picked by BR as its chosen partner to build, own, and operate the Channel Tunnel Rail Link.

January 1989
The BR Project Group, known as the Channel Tunnel Rail Link Team, was set up.

March 1989
BR announced a single route corridor (Fig. 3), which ran:

- westwards alongside the existing railway from Cheriton and through Ashford, tunnelling under the west of Ashford and emerging at Tutt Hill for the first interchange with the existing railway;
- along the planned extension of the M20 motorway as far as Hollingbourne, and alongside the existing M20 to Detling;
- north-west across open country to the River Medway, then into the North Downs Tunnel, emerging between Istead Rise and New Barn, to run alongside the existing railway west of Longfirel, through South Darenth and under the M25 motorway;
- into the London tunnel east of Swanley, tunnelling under south-east and central London to Kings Cross, with a subsurface junction at Warwick Gardens (Peckham) for Waterloo-bound international trains to join the existing railway.

10. The four proposed routes evaluated by BR.

August 1989 Cecil Parkinson appointed Secretary of State for Transport.

October 1989
Arups decided to examine alternative routes between the Channel Tunnel portal and London. The reasons for this were the perceived difficulties in tunnelling under south-east London, or in building a new international railway above ground and in an existing rail corridor, or in a combination of both. There had to be an alternative solution to that put on the table by BR.

November 1989
BR announced its intention to take the project forward as a joint venture between itself and Eurorail (made up of Trafalgar House and BICC).

March 1990
Arups published their solution, conceived in overall terms as a corridor channelling rail traffic from many points in Europe to, potentially, the whole of the UK (Fig. 4). A strategic overview was needed of the chances of linking the BR network with that of the rest of Europe, for both freight and passenger services. Indeed, it was astonishing that in the 1990s there was in the UK no overall strategic framework for roads and railways, a framework surely necessary if the main operators — BR in the case of railways - were to plan infrastructural investments on a rational basis.

In the absence of such a national plan, Arups' alternative route proposals of March 1990 were, in a sense, an attempt to fill this gap. In examining detailed alternatives within this concept, they spent a considerable amount of time consulting local authorities and a range of interest groups, all of which had a significant impact on specific route alignments.

Of course the Channel Tunnel was fixed in locational terms. However, its rail link with the rest of the country needed to have the capacity to expand (Fig. 5) and to accommodate a major park-and-ride station on the M25.

Any route also needed to maximize revenues from commuters. In this context there was immediate scope for reducing journey times by 50% for commuters to London originating from East and North Kent, and, by providing for non-user benefits, for public sector funding (Fig. 6).

Realising the difficulties that railways have in securing a commercial return, considerable efforts were made to locate a corridor which picked up sites suitable for regeneration (Fig. 7), and which also had the potential for additional value as a result of proximity to railway lines. This would enable, in principle, the offsetting of capital costs. And it was necessary to identify a corridor which minimized environmental impacts (Fig. 8). Fig. 9 shows the March 1990 Arup published corridor.

April 1990
The joint venture partners (BR and Eurorail) submitted their proposals to Government.

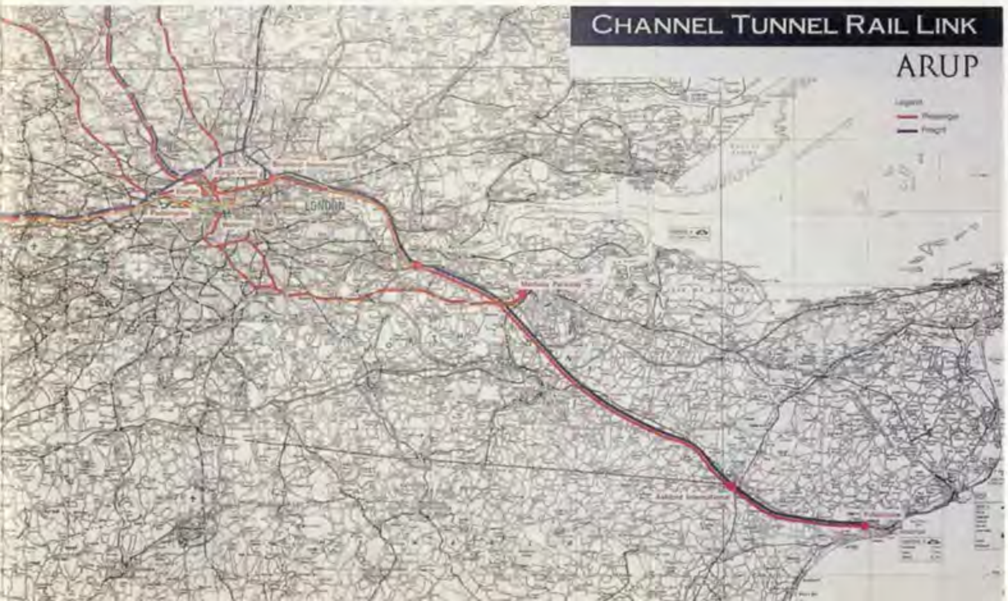
June 1990
The Secretary of State for Transport rejected the joint venture proposals. In doing so he, amongst other things, requested BR to examine again all the possible routes between the North Downs and London. Because there was broad agreement on the corridor for the new line between the Channel Tunnel and the North Downs, Mr Parkinson safeguarded this section of the route by Planning Directions.

August 1990
BR's Rail Link Project commissioned Arups to develop further their route so as to enable a valid comparison to be made with their own preferred Southerly Approach. A similar approach was made to two other promoters (Fig. 10).

- The Laing/Mowlem/GTM grouping of December 1988 joined Manufacturers Hanover and Bechtel Ltd to form 'Rail Europe' and develop the RACHEL/TALIS concepts. The group included S G Warburg & Co Ltd, G Maunsell & Partners, and the Bank of America. The original concept of the '**RA**inham to **CH**ann**EL**' proposal had been published in July 1988. A number of options were considered but the proposal was for an underground route from the Channel Tunnel at Dover direct to Rainham in a triple tunnel similar to the Channel Tunnel. The '**T**hames **A**lternative **L**ink **I**nternational **S**ystem' route had been made public in 1989 by T Bain Smith, J H Garnham Wright and R G Knott. It sought to demonstrate how a railway system could be designed to meet both the particular needs of Kent and of Britain as a whole by catering for freight traffic to the Tunnel, augmenting the commuter lines of North Kent, and providing for a fast service for international passengers should this be proved necessary.

Continued overleaf ▶

9. The Arup proposals for an Easterly Approach.



▶ *From page 3*

The June 1991 British Railways Board Report to Government comparing the four routes concluded that its own Southerly Approach was superior in business, financial and economic terms, but that Arups' proposal was the best Eastern Approach.

In October 1991, the Secretary of State for Transport announced his preference for a route 'on the lines put forward by Ove Arup'. It was clear that this was an all-Government choice since, in addition to environmental reasons, economic regeneration in the East Thames Corridor was cited as a major factor in the decision.

In March 1992, Arups were invited to join the BR consultants team to provide advice, and were responsible for the following inputs:

- route development
- station strategies, layout and design
- complete engineering design for 22km
- freight utilization
- evaluating development opportunities
- developing a consent strategy and co-ordinating planning applications
- consultation with local authorities
- involvement with public consultation
- socio-economic impact of London terminus options
- town planning impacts as part of the environmental statement
- environmental specialist inputs.

Throughout 1992, there was far more detailed investigation, led by BR, of the Easterly Approach, now Government's preferred corridor, and further intensive discussions with local authority officers along the route. To steer the route development, a set of objectives were agreed with Government, and regular rounds of meetings on three levels (ministerial, local authority members and technical officers) were held to ensure that all were carried along as options were considered and individual decisions taken. This led to a March 1993 report setting out various options, on the basis of which Government were able to make the route announcement for public consultation. This route, although different in some details, followed in general the Arup corridor and basically confirmed the robustness of the proposals. Its purpose remained to cater for international and domestic services and to be central to the East Thames Corridor redevelopment initiative.

In central London, two routes were retained for public consultation, one servicing the original Kings Cross Low Level Station proposal, and one terminating in a newly-identified St. Pancras Station option.

The six months' programme of public consultation has been the most extensive ever carried out for a rail proposal. In November 1993 a report was submitted to the Government by BR. This will provide the basis on which a route can be safeguarded by the Secretary of State for Transport in January 1984.

To page 6 ▶

11. Arup Route after the BR evaluation.

13. Union Railways Route Options 1993.

- In 1989, the London Borough of Newham had published a report entitled 'The case for a Channel Tunnel Terminal at Stratford'. The purpose was to secure the second London terminal of the international service at Stratford, with the aim of helping the regeneration of East London in general and the Stratford area in particular. Colin Buchanan & Partners were retained to develop the proposals.

Jointly with BR, Arups examined their proposals for the section between Detling and London, but on a reduced service basis, which BR specified to be:

- a twin-track railway for high speed passenger services only
- a ruling gradient of 1:90
- the servicing particularly of the existing Waterloo and the proposed Kings Cross low level stations.

The route was to be developed sufficiently for its engineering feasibility to be established, so that agreement could be reached on costs (construction and property) and on environmental impact. The joint study confirmed the robustness of Arups' proposals for the Eastern Approach (Fig. 11).

November 1990 Malcolm Rifkind appointed Secretary of State for Transport.

May 1991
The long-awaited BR report to Government, comparing the merits of the alternative routes developed by Rail Europe, the London Borough of Newham and Arups, concluded that BR's Southerly Approach was superior in business, financial and economic terms. The Arup route was considered the better of the Eastern Approach routes. BR's Board reconfirmed its decision that the right location for the second international terminal for London was Kings Cross.

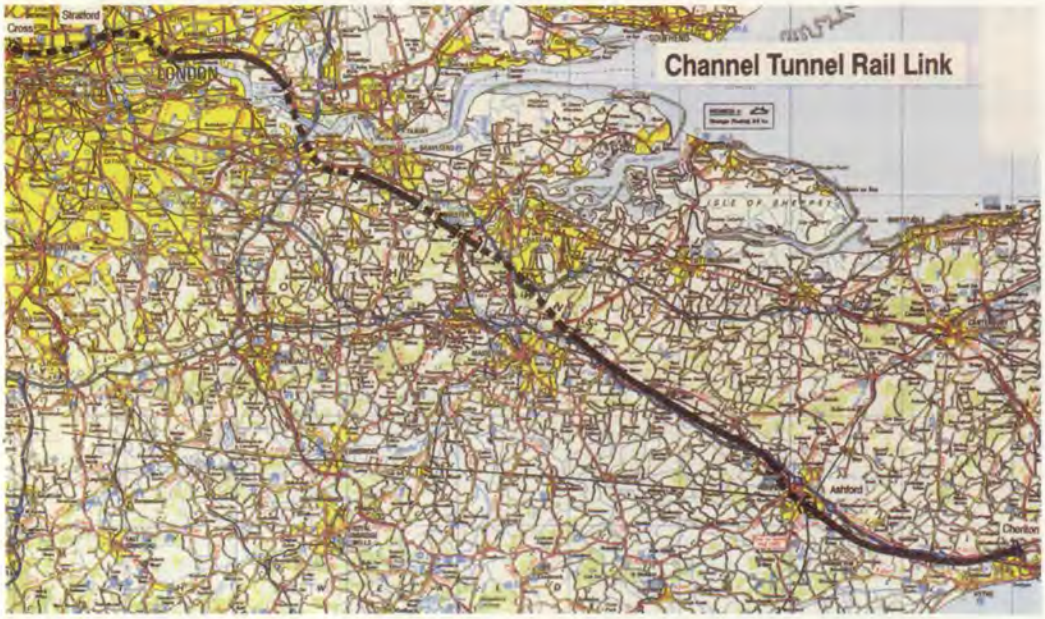
October 1991
The Secretary of State announced Government's preference for a route 'on the lines put forward by Ove Arup'. In making his statement to the House he emphasized amongst other things the substantial potential that the route offered for development along the East Thames Corridor and the fact of fewer environmental impacts than on the other routes. He went on to say that he had asked 'the Chairman of British Rail to develop the route to a standard at which I (he) can safeguard it, and to carry out a full environmental assessment... the implications for freight will be one of the matters to be considered further.' The Preferred Route (Fig. 12) comprised two parts — the previously safeguarded route between Cheriton and Detling, and the Arup-defined section from the North Downs into London.

March 1992
The Rail Link Project was re-organized to refine the Eastern Approach Route, acting as agents for the DTp. Arups joined BR's existing team of consultants.

April 1992 John MacGregor appointed Secretary of State for Transport.

July 1992
The Rail Link Project became Union Railways (UR), a BR agency company comprising public and private sector staff. UR technical experts were to work closely with six private sector consultancies — Sir Alexander Gibb, Scott Wilson Kirkpatrick, Sir William Halcrow, Mott McDonald, Ove Arup, Eurorail (Trafalgar House Technology and Balfour Beatty Projects) — plus 11 environmental consultancies in 14 disciplines ranging from aquatics to waste, which were to prepare the environmental appraisal for the project. The team's remit on the Eastern Approach was safety, business strategy, the environment, design, operation, planning and consultation.

12. The Government's preferred route, October 1991.



► *From page 5*

The Parliamentary process and the involvement of the private sector: 1994-1996

Bills placed before Parliament to grant authorization for construction are usually private bills sponsored by an individual Member of Parliament. The Parliamentary process has remained unchanged since the first Victorian railway building era. For the Channel Tunnel Rail Link, however, Government have announced that they will be the sponsors (a so-called 'Hybrid Bill'), and in their March 1993 Budget announced financial as well as political support for this major infrastructure project.

Nevertheless, before the project starts its Parliamentary process, and if its completion is to be accomplished without delay, one significant development has to be negotiated: the transfer of the project from a public sector BR proposal into a private sector promotion. Government have recognized that the attraction of private sector promotion is not solely the reduction of public sector funding, nor is this the most important function. They see private sector involvement as the most effective way of delivering managerial skills and an entrepreneurial approach to the project, to ensure the participation of private sector finance in the project's implementation.

If managerial and entrepreneurial skills are to be brought to bear on the project by the private sector, they must be mobilized when they can have a positive effect, and that means before all the elements of design and operation are committed. In June 1993 the DTp issued a consultation document entitled 'The Channel Tunnel Rail Link: Involving the Private Sector'. Arups were one of a number of groups invited by the DTp to present views on the role of the private sector in this major infrastructure project, and were subsequently called for interview. Though the consultation document centred mainly on 'Build Own and Operate' variants of involving the private sector, the experience of the Channel Tunnel itself has demonstrated that an own/design/supply build concession is inappropriate for a major infrastructure project. This has led Arups to concentrate on seeking ways and means of introducing the private sector through joint venturing with Government at the earliest possible stage, so that private sector management and entrepreneurial skills can influence the nature and character of the project. The result of this approach should ensure that this vitally important transportation link is completed on time, within budget, and to a standard of quality and performance of which all concerned can be proud.

Construction: 1996-2001

The intention is that the Hybrid Bill will be deposited in November 1994, allowing Royal Assent to be granted by the end of 1996. With a five-year construction period, it is currently expected that the Union Railway will be commissioned soon after the Millennium.

January-February 1993

Union Railways presented reports to Government on the basis of which they would be able to select a route for public consultation.

The process has been both thorough and intensive. It has considered detailed route options (Fig. 13) amounting in total to nearly 10 times the length of the corridor itself. This has produced substantial improvements in the alignment, while meeting the environmental standards commonly applied to other major infrastructure schemes. The costs have been significantly reduced, and the various options now fall within a range of £2bn-£3bn. The UR reports did not make recommendations. The detailed remit set by Government meant that UR was required to identify a series of options, satisfying different criteria, which would allow Ministers to make an informed choice.

March 1993

The Secretary of State reported to Parliament on 22 March 1993, and it is interesting to note some of his key points. He made it clear that:

- The High Speed Rail Link was to go ahead as a joint venture between the public and private sectors, with UR forming the vehicle for this joint venture.
- Government was prepared to provide substantial public sector support for the construction of the Link.
- The next stage was to be a thorough process of public consultation, to be led by UR and to be completed by mid-October 1993.
- Government intended then to introduce a Hybrid Bill into Parliament.

Finally Mr MacGregor stressed that pressing ahead rapidly in this way would enable the Rail Link to be opened by around the turn of the century.

In his statement, Mr MacGregor announced the route which he wanted to be subjected to public consultation (Fig.14). The main differences were:

- that it would pass to the north of Ashford
- that it would then, broadly speaking, follow the Arup alignment across a bridge over the Medway
- that it included two alternative routes from the Barking Portal to London Kings Cross/St.Pancras.

Conclusion

Clearly during the past 18 months very considerable progress has been made in selecting the best alignment between the North Downs and London. At the same time, improvements have been made to the previously safeguarded BR route between Cheriton and Detling. During this period there has been extensive discussion with local authorities and other interested parties, all of which have built on the discussions which Arups had started in 1990, during the development of their Eastern Approach. It is therefore not surprising that the March 1993 route announcement was reasonably well received, and this was obviously a good start for the subsequent public consultation process. The other issue of considerable significance is the apparent acceptance by the Treasury of the need for public sector funding for the Union Railway. It has taken a long time to get this acceptance. While the concentration of effort has been on the route selection process, little progress has been made on the securing of private sector involvement. The Government's view seem to remain that this railway project should go ahead as a joint venture between the public and private sectors. But how will this be effected? The Secretary of State indicated in early November that a competition would be held in 1995 to select a private sector partner to design, construct, and operate the Link. Simultaneously he stated that Union Railways would become part of the joint venture, as would BR's european passenger services business. While the saga of the Channel Tunnel Rail Link, already six years long, is far from over, Arups' role in influencing the alignment of the high speed railway into Europe will not be forgotten.

14. Government's Preferred Route for Consultation, March 1993.

Credits

Client 1989-1991:
Ove Arup Partnership
Designers:
Arup Economics & Planning
Povl Ahm, Oliver Bevin, Mark Bostock, Ken Cole, John Couch, Rob Evison, Richard Foster, Steve Harrison, Terry Hill, David Joy, Denis Kirtley, Michael Lewis, Peter Nono-Bwomono, Malcolm Noyce, Jim Nyhan, Trevor Slydel, Graeme Smart, Peter Speleers, Paul Tomlinson
Consultants:
Alastair Dick, Colin Stannard
Parliamentary Lobbyists:
Decision Makers (Maureen Tomison)

Client 1991-1993:
BR/Union Railways Ltd.
Designers:
Ove Arup & Partners
Povl Ahm, Mark Bostock, Terry Hill, Phil Lee
Engineering team: Paul Barlow, Joanna Bole, John Border, Robert Clapham, Brian Coyle, Phil Dauncey, Richard Foster, Clive Gaitt, Nigel Hailey, Lise Hearn, John Henry, Tim Hocombe, Nick Khosla, Peter Knight, Paul Lacey, David Lewin, David Loosemore, Angus Low, Jason Manning, Tony Marshall, Alan Mason, Strachan Mitchell, Graeme Powell, Nick Rabin, John Redding, Corey Russell, Mike Russum, John Seaman, John Shaw, Neil Shepherd, Nick Sidhu, Robert Stack, John Stowell, Bob Williams

Planning team: Claire Beedle, Maggie Gatland, David Joy, Andrew Marsay

Other specialist teams
(1) Input to UR Environmental Assessment:
Planning effects: Lorna Andrews, Richard Coburn, Adrian Gurney, Andrew Rumfitt, Mark Smith, Corinne Swain, Ray Willis
Atmospheric pollution: Ingrid Byng, Neil Jenkins, Steve Jones, Sue Blanche, Rob Paris
Construction noise: Chris Manning
Socio-economic impact (London Terminal): David Wickens

(2) Intermediate stations: Ahmed Bouariche, David Johnston, Graeme Smart, Stewart Jenkins, Gordon Henderson

Administration: Cheryl Lawrence, David Lowes

Illustrations:
1: Mary Evans Picture Library;
2, 4-8, 10: Denis Kirtley;
3, 9, 12, 14: © Crown copyright;
11: Peter Warren;
15: QA Photos

15. Arrival of the first 'Eurostar' train at the UK terminal from France.

The Western Morning News

Peter Bailey

1. View from the west.

2. Site plan.

Introduction

The Western Morning News Company, part of the Daily Mail Group, has been publishing newspapers in England's West Country since 1860. The company produces two principal papers daily: *The Western Morning News* and *The Evening Herald* — each with a circulation of around 60 000 copies. Together they provide a uniquely complete service, combining local with national and international news.

Having rapidly outgrown their previous city centre location in the only building in central Plymouth to survive the World War 2 Blitz, the company purchased a greenfield site in Derriford, just to the north of Plymouth, for the location of their new headquarters. Nicholas Grimshaw & Partners were selected from a list of four invited architects to design the building.

Brief

A completely new state-of-the-art newspaper administration and production facility has complex technical requirements, and these were defined in the brief. The primary objectives of the building, however, were:

- to enable the company to rationalize their working process through the introduction of new technology
- to give the company a high profile identity and good public image.

In May 1990 the rest of the design team was appointed, with Ove Arup & Partners responsible for structural, civil and geotechnical engineering. The initial budget was set at £14.9M, and the programme defined as follows:

- Appoint management contractor: March 1991
- Commence construction: June 1991
- Complete primary structure: February 1992
- Handover: December 1992

Architectural design concept

While not denying the identification of the building's profile with Plymouth's historical Naval associations, the architects generated the shape of the building from site influences. The north elevation follows the steep curve of the site on that side, and is mirrored on the south to create a symmetrical plan. The resulting curve on plan maximized views over Dartmoor for the office workers.

As with its predecessor, the *Financial Times* building in London's Docklands, the walls were glazed to allow, especially at night, views of the printing press for passers-by on the Plymouth to Tavistock road. In contrast however, the side walls were curved in elevation so that views of the press from the visitor approach road below would not be interrupted by reflections.

At this stage the nautical theme began to take hold and an observation tower, later to become the boardroom, was added. From the tower there are impressive views over Dartmoor and back towards Plymouth Sound, a visual link with the historical focus of Plymouth.

Overall form

The 15 000m^2 building incorporates 5000m^2 of office accommodation on three floors at the eastern or 'bow' end. The office space, a mixture of open plan and private, wraps around a full-height atrium. Additional facilities include a restaurant, meeting rooms, and a fitness centre.

The production facilities are located in the 'stern' of the building. The new £10.9M Rockwell T60 *Headliner* press dominates this section, occupying the full three storeys and symbolically forming a 'ship's engine room'. The press weighs over 500 tonnes, is 42m long, and can print over 60 000 copies per hour. This now gives the company the capacity to print the *Daily Mail*, the *Mail on Sunday* and several other local newspapers.

Structural concept

The aim was to create a 'building within a building', thus simplifying the construction interface between the curved external glazed façade and main floor structure. The internal building is a self-supporting reinforced concrete frame with the external an almost free-standing steel and glass enclosure, the two connected only at roof level at the tops of the columns. Loading is shared between these elements by bracing in the roof plane.

3

4

The glass wall

There is little doubt that the intricacies of designing and installing the glass façade presented the greatest structural engineering challenge in the building. This compound curvature, non-reflective glass enclosure in the Pilkington *Planar* system is unique, and has been described[1] as the culmination of the glazing revolution begun by Mies van der Rohe over 40 years ago. Each element had to be carefully designed not only to resist the structural loading but also to be sufficiently adjustable to overcome the myriad of construction tolerances demanded by the three-dimensional shape. The design of each component can be examined individually:

5

Glass

Over 650 panels of Pilkington *Planar* glazing form the skin of the building, giving it shape and identity. In the office section, the geometry of each side wall was defined as a segment of a torus, a doughnut-shaped surface of revolution set out by two radii. By choosing a mathematically defined shape, repetition of elements was possible. Flat glazing panels are used to form a faceted approximation to the toroidal surface, with set-out points at the intersection of the joint lines defined by computer to the nearest millimetre. The resulting glass panels are tapered very slightly, varying in width from 2m at the top of the highest panel to 1911mm at the bottom of the lowest. In the office section, every glass panel is identical to its neighbour on any given level.

The shape of the bow is defined by the intersection of the two toroidal sides of the building, necessitating two rows of non-standard glass panels; in the production section, however, the wall is curved outwards only and can be defined by a single radius. Here there are three columns of glass panels between each 6m grid, making all panels in this section identical and 2m square.

6

Glazing boss

A four-legged spider-shaped stainless steel glazing boss is used to support the glass via the *Planar* fixings. Due to the amount of repetition it was decided to cast them, and the 'lost wax' technique was chosen. This allowed the architect to sculpt the boss into an organic shape, and achieve a very high quality finish after polishing. The detailed design of the boss was developed by Briggs Amasco Curtainwall Ltd. (BACL) from scheme drawings of the design team. BACL chose to build a number of adjustable components into the boss to cater for the construction tolerance difference between the supporting structure (set out to ±5mm) and the requirements of the glazing (set out to ± 1-2mm).

3. The press hall through the glass.

4. Main entrance, with the boardroom above.

5. Interior of second floor office.

6. Close-up of glazing boss.

7

8

Cast glazing arms and struts

The glazing boss is in turn supported by 2m long cast structural arms fanning out each side of 'tusk' columns (see below), and a 600mm long cast strut directly behind each tusk. These castings provide the horizontal restraint to the glazing necessary to resist wind load. The weight of the glass, the boss, and the arms themselves is supported by stainless steel hanger rods.

As the Menil Gallery in Houston (Renzo Piano/Peter Rice) had been a source of inspiration, a bony, sculpted shape evolved for the castings using the same material, cast ductile iron (spheroidal graphite — SG). A sand casting process was used and this resulted in a moderately textured surface, contrasting with the highly polished cast stainless steel boss.

The cast arms and struts are spaced at 2m vertically. Each strut is identical throughout the building, but the arms are identical only on the singly curved (production) sides. The arms on the double curvature office wall vary in length by a small amount between every level and this was catered for by providing a straight segment on the casting which was segmentally shortened on the mould.

Positioning the ends of the arms to a point in space to a maximum tolerance of ±5mm was achieved with a threaded ball joint/clamp connection to the tusk. This allowed adjustment of the position of the end of the arm in all three dimensions before being 'locked off'.

Tusks

From a very early stage in the design the architects began drawing curved bony external columns as a major feature of the building. Tapering was introduced as a physical representation of their cantilever function, and this resulted in a shape with a strong resemblance to an elephant's tusk, hence the name. The 15m high tusks are situated on grid lines at 6m centres around the building. Each is identical except for the 'bow' tusk which has to deal with unique loading conditions and geometry. The tusks comprise two 194mm diameter CHS sections rolled to a radius of 21m and connected by tapering 8mm side plates. The junction of the plates and the CHS sections was filled with weld metal and ground flush, forming an apparently seamless, homogeneous section of exceptional fabrication quality.

Each tusk was designed to deal with varying loading conditions and geometry. Asymmetric wind loading in particular was examined in great detail, with the allowable movements of the glass fixing points limited to less than 20mm normal to the glass and 2mm parallel to the glass.

Foundations and ground slabs

Conventional pad foundations and ground bearing slabs, 125mm thick beneath the offices and 175mm thick under the production area, are used throughout. The slabs in the latter are designed to resist wheel loads from fork-lift trucks and uniform loads of 25 kN/m^2 from the storage of paper rolls.

Concrete floors

The office superstructure floors are generally 250mm thick reinforced concrete flat slabs on a 6m x 6m radial grid, with 350mm diameter reinforced concrete columns.

The production area floors are 600mm deep ribbed slabs supported by a 12m x 6m grid of 600mm diameter columns. Ribs are provided at 1.5m centres. Transverse load between ribs is carried by a 125mm deep slab, removing the need for central transverse ribs. Full use was made of the 10m long 'hollow' between the ribs for services distribution.

Roof

The roof is supported by primary steel beams (690 UB) on the grid lines at 6m centres, spanning 17m maximum; the beam is rolled to a radius of 125m in the centre and 30.5m at the edges. Circular hollow sections provide bracing in the roof plane.

The press platform

The new press is designed to sit on a 50m long, single-storey concrete table, or press platform, with the paper reel stands underneath, supported by a 1m deep by 4m wide raft footing sitting within a swimming pool-shaped concrete isolation chamber lined with *Mafund* vibration isolation pads. The concrete chamber in turn is founded on the intact slate. The press platform itself is a conventional concrete structure with beams up to 1m deep. The deflection criteria for the press were extremely stringent, with 3mm maximum allowable deflections from all causes, and 1mm maximum allowable differential deflections between press support points. Detailed short and long-term deflection analyses were conducted and deflections of comparable magnitude were estimated. The client was advised, however, to allow for periodic re-levelling.

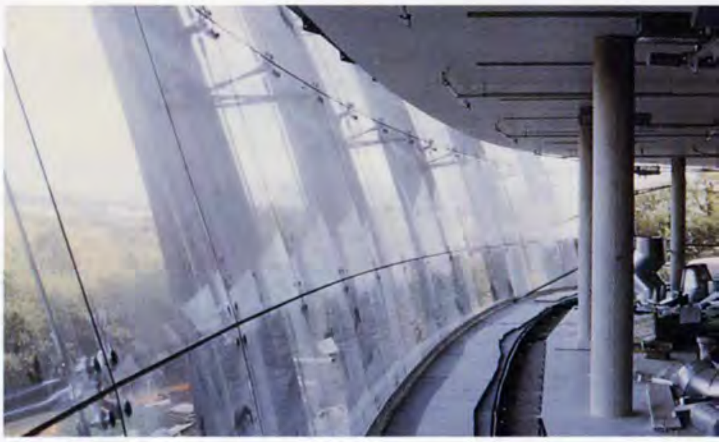
A detailed vibration analysis was also conducted to test the dynamic performance of the 12m high press and table system. The coupled frequency of just under 3Hz was sufficiently close to the operating frequency of the press (2.5Hz) to warrant a detailed response calculation, and this proved the behaviour to be within acceptable limits.

9

11

12

10



13

7. The 'bow'.

8. The van loading bay.

9. Assemblies of tusks and glazing arms, with temporary restraint angles.

10. Construction, viewed from the west, December 1991.

11. Concrete columns in the production area, December 1991.

12. Tusk assembly being lifted into place, February 1992.

13. Glazing installed, first floor office, October 1992.

14. The 'ship' at night.

Construction

Work began on site in July 1991 with the excavation and the concrete frame. Particular attention was paid to the finish quality of the concrete and a high standard was achieved, particularly in the rib slab areas.

Installation of the central bays of the steel roof commenced in November 1991. Fit-out work was started under this central covered zone whilst the fabrication of the steel tusks and the castings for the perimeter façade were completed. The tusks, fully fitted with all castings and hanger rods, were brought to site under police escort from the Plymouth fabrication works on a lorry, from which they were directly lifted into position.

Conclusion

The Western Morning News building was completed on time and on budget in December 1992. It is already a well-known landmark in Plymouth and has proven successful in raising the public awareness and profile of the company. The building is operating successfully and is now recognized as the premier newspaper facility in the West Country.

Reference

(1) PAWLEY, M. *et al.* Nicholas Grimshaw. *World Architecture,* No.23, pp.34-57, May 1993.

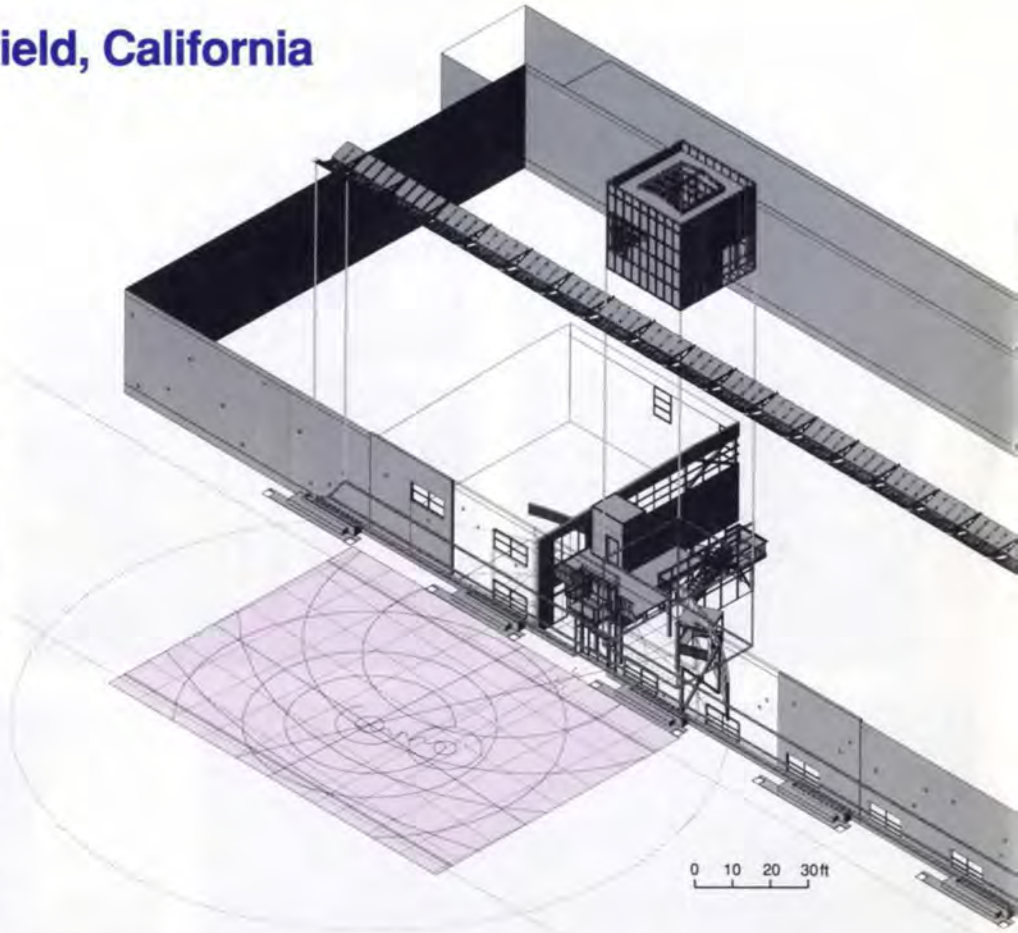
Credits

Client:
The Western Morning News Co. Ltd.
Architect:
Nicholas Grimshaw & Partners Ltd.
Structural, civil and geotechnical engineers:
Ove Arup & Partners Peter Bailey, Tom Dawes, Peter Rice, Faith Wainwright, Paula Youngs (structural), Mark Bidgood (civil), David Pascall (geotechnical), Paula Youngs (site engineer)
Quantity surveyor:
Davis Langdon & Everest
Services engineers:
Cundall Johnston & Partners
Management contractor:
Bovis Construction Ltd.
Steelwork sub-contractor:
Blight & White Pty Ltd.
Concrete sub-contractor:
Diespeker
Glass wall sub-contractor:
Briggs Amasco Curtainwall
Photos and illustrations:
1: Nicholas Grimshaw & Partners; 2: Reid & Peck;
3, 12: Peter Bailey; 4, 5, 7-11: Peter Mackinven;
6, 13: Faith Wainwright; 14: Paul Grayshon.

14

The APS project, Fairfield, California

Alisdair McGregor
Pam Brandon Ehart



Introduction

In 1989, Ove Arup & Partners California's San Francisco office were approached by Gregory Kiss of the architects Kiss Cathcart Anders (KCA), of New York, to design a new production facility for the manufacture of photovoltaic (PV) panels. The production line for the panels, known as the 'Eureka' line, was being developed in Trenton, New Jersey, by Advanced Photovoltaic Systems (originally Chronar Corporation), to produce panels utilizing innovatory, state-of-the-art technology. After numerous changes, including the loss of the original site, the project got off the ground at the end of 1990.

The building is located in Fairfield, California, halfway between San Francisco and Sacramento, in the Solano Business Park. It is the first building of its kind: the world's largest production facility for photovoltaic panels in terms of potential output, which is expected to be 10MW of PV panels each year.

The process

The photovoltaic process has been developing since the early 1960s, when it was first used to power satellites. It is a highly appropriate technology for the 1990s, where environmental issues are pushing to the forefront of world concern, but PV applications have previously been hampered by prohibitive costs and the technical difficulties of power conversion and installation. Though their use has until now been extremely limited, APS' new panels will allow the technology to have more widespread applications.

The process begins by laying down a transparent conductive oxide on a 2.5 x 5ft (750 x 1510mm) glass substrate. Amorphous silicon is then deposited on top of the conductive film in one sequence, after which a metal back contact is applied to the layers prior to the final encapsulation. The thin film layers are laser-scribed to provide automatically the series interconnection between cells, achieving the desired module voltage without additional costly processing. Finally, the layers are encapsulated with EVA in a glass/glass module designed to withstand long-term environmental exposure. When sunlight hits the panel, the molecules of light-sensitive silicon become excited, resulting in electrical current that is routed into circuits.

The architectural concept

The 69 000ft^2 (6410m^2) structure for APS houses an assembly line for glazing panels, plus warehouse space in which to store the panels before and after they are glazed. The major building elements are organized in parallel masses (Fig. 1). A serrated mechanical/service 'bar' sheathed in stainless steel adjoins the main mass of the building (see Fig. 14 overleaf), whilst another stainless steel bar engages the building on the roof, enclosing roof equipment and terminating in an access stair at the east end. At the south side of the building is a pedestrian area shaded by a stainless steel and PV glass awning (Figs. 2, 7). The entry is marked by a pattern, cast into the pavement, describing the path of the sun overlaid with a diagram of the photovoltaic effect at the atomic level (Fig. 3). The inhabited areas (control room, conference room, office, lockers, and vertical circulation) form a cluster centred around the control room. The latter is housed in a cube sheathed in PV glass, including a PV skylight, which interpenetrates the volume of the production facility (Fig. 4).

The cube can generate enough power to air-condition itself from its own skin and the PV awning. By extensive use of PV panels and sheet metal, the architecture reflects the new technology produced within and the craft of the major investor.

Building services

One of the primary aims is to produce PV panels cost-effectively. Thus an essential parameter for the building systems is that they have a low first cost, and more importantly, that their life cycle cost is minimized.

Arups developed building systems which could accommodate both immediate and future changes, since APS' production line layout was already changing during design and construction. A pipe rack and electrical tap-off bus-bar trunking surrounds three sides of the production area at a high level, with potential to serve many areas should the production line change. Pipe and cable services extend from a main rack to connection points on the production line.

3

4

5

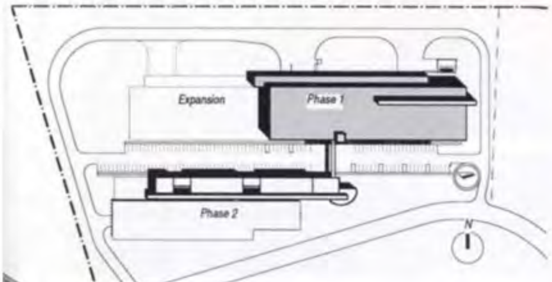
3. Solar paving pattern at the building entrance.

4. Interior of 'cube' control room.

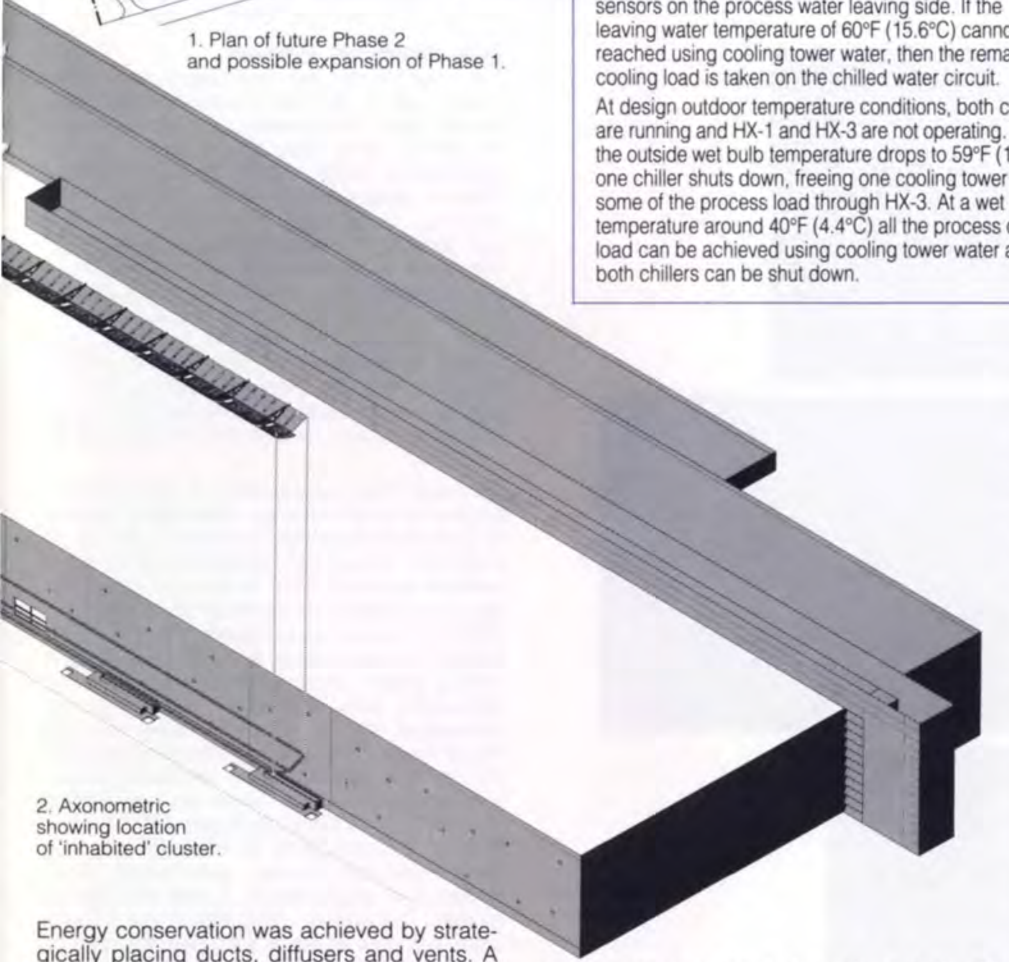
5. Production area interior, with the braced frame and main duct providing colour.

6. The 'sputtering' area of the production line, beneath the main air-handling unit, where the aluminium thin film is deposited onto the glass.

7. PV modules installed on the awning.



1. Plan of future Phase 2 and possible expansion of Phase 1.



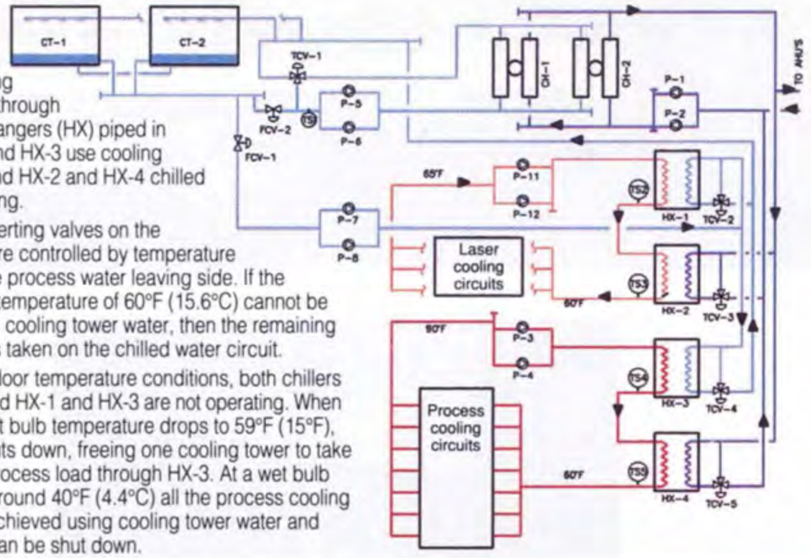
2. Axonometric showing location of 'inhabited' cluster.

System operation

Process cooling water passes through two heat exchangers (HX) piped in series; HX-1 and HX-3 use cooling tower water and HX-2 and HX-4 chilled water for cooling.

Three-way diverting valves on the cooling side are controlled by temperature sensors on the process water leaving side. If the leaving water temperature of 60°F (15.6°C) cannot be reached using cooling tower water, then the remaining cooling load is taken on the chilled water circuit.

At design outdoor temperature conditions, both chillers are running and HX-1 and HX-3 are not operating. When the outside wet bulb temperature drops to 59°F (15°F), one chiller shuts down, freeing one cooling tower to take some of the process load through HX-3. At a wet bulb temperature around 40°F (4.4°C) all the process cooling load can be achieved using cooling tower water and both chillers can be shut down.



8. The cooling system.

Energy conservation was achieved by strategically placing ducts, diffusers and vents. A central spine duct supplies conditioned air to the production area, but is not intended to condition the whole space (Figs. 5 & 6). Jet diffusers can be adjusted to direct cooling air to occupied areas on the floor, while unoccupied areas and the upper half of the space will be allowed to rise in temperature. Roof vents located above the tin oxide and silicon deposition ovens allow the convective heat load from the ovens to escape in the summer, reducing the load on the chillers and conserving energy. Low level wall vents open to enhance the natural ventilation.

For the control room, the 5ft x 2.5ft PV modules which APS manufactures at the plant are used as exterior walls; additional modules which contribute power are installed on the awning across the front of the building (Fig. 7). The PV modules are connected into the building electrical system through an inverter. APS will monitor the power generated by the panels through a series of transducers and a computer, and Ove Arup & Partners, APS and KCA are involved in continuing research to discover new and more effective ways to use the modules.

Cooling system

The principle of the cooling system design is to use the project's cooling towers as the source of process cooling and minimize the use of chillers (Fig. 8). This will result in significant electrical energy savings. The microclimate of Fairfield is ideal for efficient evaporative cooling. Although the design dry bulb temperature is 98°F (37°C), the design wet bulb is 69°F (20.5°C). For 3000 hours per year the wet bulb is below 50°F (10°C). Also, Fairfield's location in the Sacramento/San Joaquin River Delta means that in summer the evening and night time temperatures drop significantly as the cool marine air pushes up the Delta from San Francisco Bay in the late afternoon. Since this means that at night there will often be little or no demand for a chiller to cool ventilation air, one of the towers can be freed for process cooling.

The four heat exchangers are all stainless steel plate and frame units. Plate heat exchangers were selected to minimize the temperature difference between cooling water and process water and to give the ability to increase capacity by adding plates in the future. Two 180ton (640kW) chillers are used.

Life cycle costing

During design development APS asked for a comparison between a separate process cooling circuit system and package air-cooled chillers. Because the latter worked fine at their Princeton test facility, APS assumed they would surely cost less than the complex system proposed for Fairfield. However, the life cycle cost analysis showed a payback period of three or four months for the system as designed.

6

7

9. The building from the highway at dusk.

The structural scheme

The main block: the production and warehouse area, is basically a concrete box using 'tilt-up' panel construction. The roof is a system of 4ft (1.2m) deep glulam timber girders spanning up to 60ft (18m) with 4 x 16in (100 x 400mm) timber purlins at 8ft (2.5m) centred between. A plywood membrane forms the roof diaphragm. Resistance to wind and seismic loads is provided by a combination of concrete walls and interior concentric braced frames. This structure was defined as the most cost-effective, both in materials and speed of construction, although it should be noted that the present shortage of old-growth lumber in the Pacific Northwest has sharply reduced the use of such large sawn sections.

Although tilt-up construction is very common for factory type buildings, the challenge was to accommodate the architect's desire to avoid the 'boring box' syndrome associated with this structural type. To this end, the architect incorporated many randomly placed 12in (305mm) square glass blocks, through which sunlight shines during the day producing a shifting pattern of squares on the floor of the production area, and which also create an interesting display at night when lit from inside the building (Fig. 9). Also incorporated into the wall panels are the necessary doors, windows, louvres, etc. Since the wall panels are only 7¾in (200mm) thick and 26ft (8m) tall, and were required to function for in-plane shear (seismic) forces, out-of-plane wind forces, and gravity loads, it was decided to connect the panels using cast-in-place concrete columns at each joint, as opposed to the more conventionally accepted pin-welded connection. Doing so enabled the panels to work together as a single unit, thereby alleviating our problems.

The panels were laid out on the cast slab-on-grade, which served as a form for the inside face of the panels, with all the door frames, glass blocks, etc., positioned prior to reinforcement placement. The ledgers for the timber roof system were also set into the panels at the casting stage. After the panels had set up to the design required strength they were lifted into place using a crane. This was achieved by means of special inserts cast into the panel at reinforced lift points. Cables from the crane snap into the inserts, and, with a noise akin to a vacuum-sealed jar being opened, the panels leave the slab (Fig. 10). After being guided into place (Figs. 11 & 12), they are propped up until the slab edge strip and connecting pilasters are cast (Fig. 13). With the crane and a crew of five men, the entire building shell rose into place in 1½ days. The finishing touch to the panels was a medium sandblast, exposing the aggregate carefully chosen by the architect.

The structural design of the APS facility also includes safety measures. To make the PV panels, the production line at utilizes silane, a pyrophoric gas which ignites on contact with air. To protect the building structure and adjacent highway from an explosion, the gas must be stored in cylinders in a blast-proof hazardous process materials (HPM) enclosure. This consists of a 2ft (600mm) thick C-shaped wall, 10ft (3m) high, with a chamfered overhang at the top to deflect blast waves

10

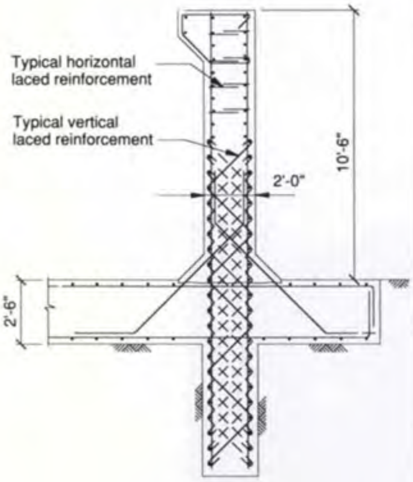
11

12

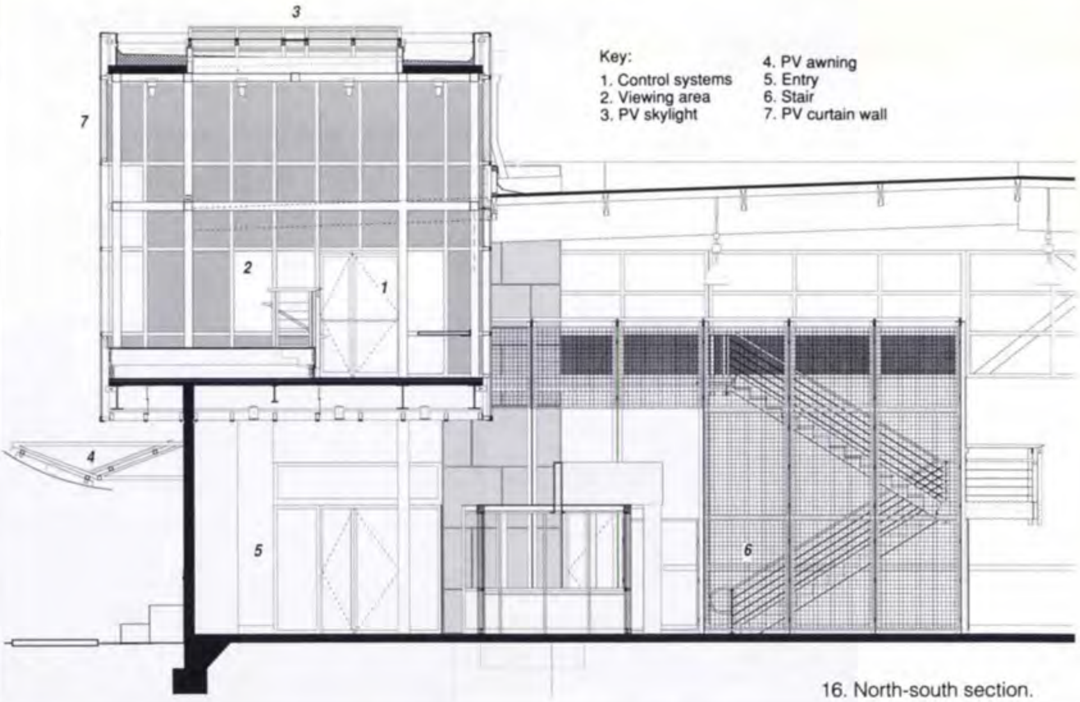
13

10-13. Tilt-up panel raising.

14. Serrated service bar at rear of building.



15. Cross-section through blast wall.



16. North-south section.

back into the enclosure. About 20ft (6m) away from, and parallel to, the blast wall is a thermal wall, which serves to absorb most of the blast's reflected energy.

The blast wall itself is designed to protect the building from 'catastrophic cylinder failure', a worst case scenario. The cylinder will fail at 1120 lb/in^2 gauge (at each gravity) (7722kN/m^2), resulting in a 10ft (3m) diameter fireball lasting about ½ second. With a cylinder-to-wall stand-off distance of 2ft (600mm), this blast is estimated to be equivalent to one ton of TNT exploding at a distance of 100ft (30m). An explosion of such high pressure for a very short duration is termed an 'impulse load'. Since the response time of the structure is very long in comparison to the duration of the load, a very ductile design is required.

The wall's deflection due to the blast load further amplifies the effect of the explosion, and a dynamic analysis of the structure is necessary. It was assumed in the analysis that the concrete would spall completely off the surface of the wall, leaving the reinforcement exposed. Another aspect of this type of explosion is that fragments of the cylinder may become missiles and penetrate the wall. To guard against this, its thickness was made at least three times the estimated penetration of the fragment.

To achieve the required ductility in the wall, special care was taken in detailing the reinforcement. Transverse bars were 'laced' through the perpendicular bars at 45° in overlapping patterns, resulting in a highly intricate reinforcing cage that required careful construction sequencing (Fig. 15). Overturning of the wall is resisted by the thickened slab of the HPM enclosure combined with the downward component of the blast load.

Special design provisions were also required for the flammable liquids storage room, due to the H2 occupancy category imposed by the UniformBuilding Code. To achieve the required containment at a given static pressure load, the room was encased in 10in (250mm) thick concrete walls, a 12in (300mm) thick floor slab and a 10in (250mm) thick concrete ceiling. The latter contains a large concrete 'chimney' that terminates in an explosion venting hatch cover, designed to blow off at a given low pressure, thus relieving the pressure on the inside of the room.

17. Reception area 'cube' viewed from end of production line.

Conclusion

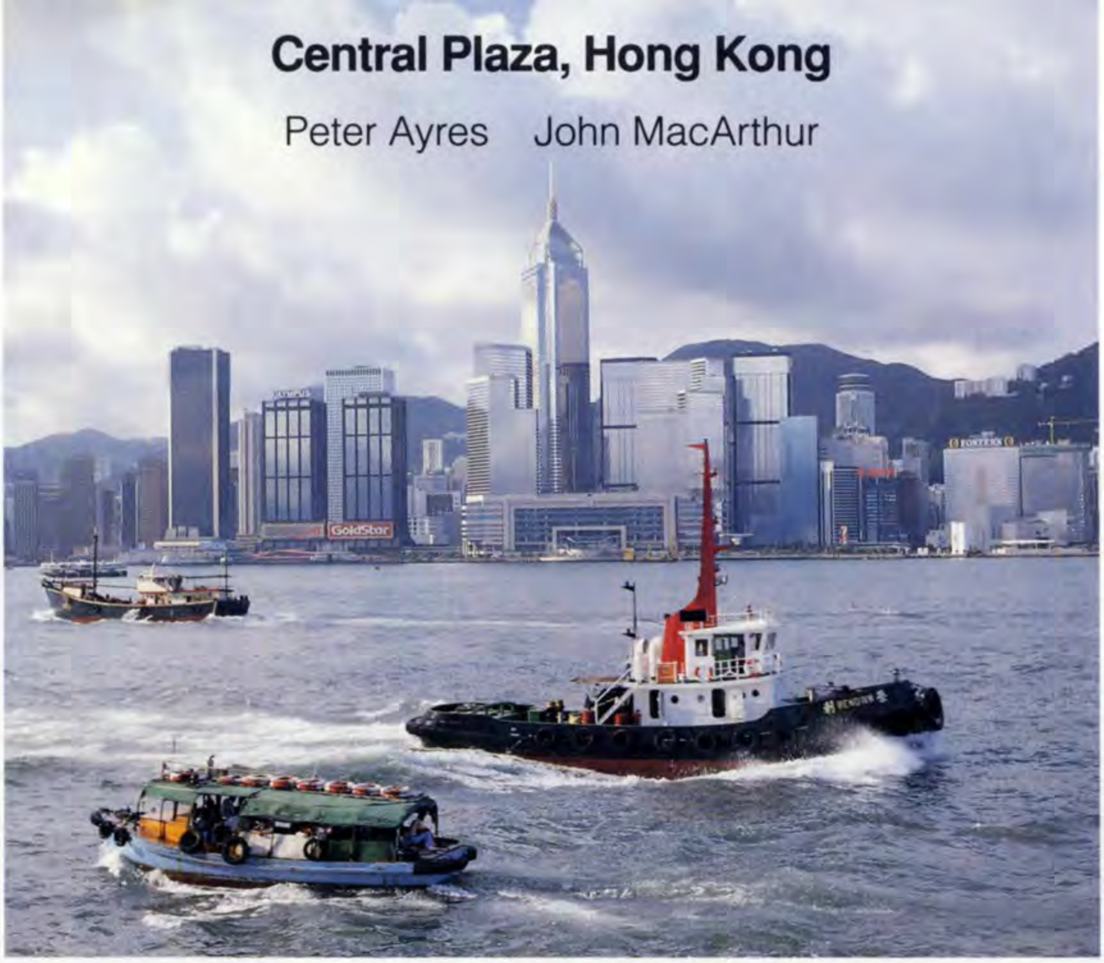
Photovoltaics, or solar-generated electricity, is an emerging technology that will have a major impact on architecture. With this technology, buildings will become active participants in creating their internal and external environments. Research continues on how to use PV panels most effectively as building skin while they simultaneously provide power for a building. KCA and Ove Arup & Partners, in conjunction with APS, have applied for Federal funding to design, analyze and construct a building which maximizes the use of PV panels.

Credits

Client:
Advanced Photovoltaic Systems
Architect:
Kiss Cathcart Anders
Structural and services engineers:
Ove Arup and Partners California Ltd.
Alisdair McGregor, Jerry Frias (mechanical),
Jack Howton (plumbing), Peter Balint (electrical),
Pam Ehart, Peter Lassetter (structural)
General contractor:
Devcon Construction
Mechanical sub-contractor:
Bell Products
Electrical sub-contractor:
Frank Electric
Illustrations:
1, 2, 16: Courtesy Kiss Cathcart Anders;
3: © Jeremy Green; 5, 7, 14, 17: Mark Darley;
4, 6, 9: Photos Richard Barnes;
8, 15: Ove Arup & Partners California;
10-13: Photos Pam Ehart

Central Plaza, Hong Kong

Peter Ayres   John MacArthur



1. The building across Victoria Harbour.

Introduction

Land auctions in Hong Kong are major public events, and it was at one such occasion on 28 January 1989 that the site for Central Plaza was acquired (Fig. 2). The purchasers were two major developers, Sun Hung Kai Properties Ltd. and Sino Land Co. Ltd., who had only agreed to form a consortium to develop the site jointly during the auction. They paid a Hong Kong record price of US\$61 000/m^2 for the 7000m^2 site, making the total price US\$430M. Daily interest charges of US\$120 000 provided a major incentive to complete the building works as quickly as possible. Shortly after the auction took place, a third developer, Ryoden Property Development Co. Ltd., joined the consortium. The land cost alone was to represent approximately ¾ of the final total project cost, but such an apportionment is normal in Hong Kong.

At the time of purchasing the site, the owners had no architectural concept in mind and were not entirely clear as to the use of the building. A substantial part of the accommodation would be for offices but whether any part should be for hotel use was unclear.

Arups were appointed as structural engineers shortly after the site had been purchased, commenced initial design work on the basement, and provided technical advice to the developers during their assessment of a number of submitted architectural designs. Four architects were invited to prepare schemes and, after two months, the local firm of Ng Chun Man & Associates was appointed as both concept and design architect.

In December 1992, just under three years after the purchase of the site and the appointment of the design team, Central Plaza received its full Occupation Permit from the Building Authority signifying practical completion. The achievement of this programme owes much to the interactive development of the design: the developer, consultants and contractors all working closely together with the single aim of achieving a timely and cost-efficient completion of the new building.

2. Location plan.

Design development

Central Plaza is in the Wan Chai district, about 1km to the east of Central and approximately 100m from the northern shoreline of Hong Kong Island. There are a number of high rise buildings nearby, the tallest being the 180m office tower in the Convention Centre Complex directly to the north of the site, separating the new development from the Harbour.

After site purchase, the developers quickly decided that a hotel or serviced apartments would not be financially viable and that only offices should be included. The building had to be tall and suitably oriented to avoid obstruction of views by its high neighbours.

As the final content and nature of the project would take some time to emerge, the provision of any sort of detailed brief was not possible at the outset of Arups' appointment. However, several factors that would have a major impact on the structure soon became apparent:

(1) The majority of the total accommodation would be provided in a single tall tower.

(2) The space at the lower levels of the tower would be as open as possible to maximize beneficial usage of the public dedicated space at ground floor.

(3) A basement occupying the plan envelope of the site would be required to accommodate vehicular parking and services provisions.

(4) Construction had to be fast: the investment in the site meant that work had to commence at the earliest opportunity and proceed as quickly as possible.

Various plan forms for the tower were considered by the design team and finally a triangular shape was selected; this both allowed two of the main façades to have direct harbour views between the adjacent buildings and gave the building a slimmer appearance. The three corners of the triangle were then curtailed to provide a better internal space and the possibility of a greater number of corner offices.

Having decided upon the triangular plan, the developer's initial concept was for a tower having a height to the base of its mast of 340m, with a floor plate area of approximately 1800m^2 and a slenderness ratio of more than 1:6. An extremely stiff and strong external frame would be needed to resist the high lateral wind loads and to reduce building movements to satisfactory limits. After several options had been studied, it was decided that an externally cross-braced framed tube fabricated from structural steel tubes, infilled with high strength concrete, best fulfilled the client's requirements.

The use of steel minimized member sizes and, most importantly, was considered to offer programme advantages over reinforced concrete, the concrete infilling being carried out several floors below the steelwork erection.

The floors were to be of conventional composite construction with primary/secondary beams carrying metal decking with a 160mm thick reinforced concrete slab. A floor-to-floor height of 4m was adopted. The core was also of steelwork, designed to carry vertical load only. The core arrangement was ideally suited for construction in steelwork modules.

It was a requirement that the lower storeys be opened up for better public circulation, and this led to the tower base being 50m tall above ground level. The main braced tube of the tower would spring from the top of this base. Pairs of columns were to be positioned at each corner of the tower, and these in combination with the transfer trusses on each façade at the top of the base would transfer lateral loads to the foundations in portal action.

The total weight of steelwork for the finally adopted scheme was estimated to be of the order of 24 000 tonnes, or 150kg/m^2 of floor area. A large percentage of this weight was in the tower base.

In July/August 1989, there was a sudden reduction in land values in Hong Kong and this necessitated a financial review of the development proposals. Construction of a diaphragm wall was under way but, whilst detailed design of the building was by now in progress, there was still the possibility that schematic revisions could be made, providing the necessary decisions could be arrived at quickly. As a result of these studies it was decided to reduce the height of the superstructure and increase the size of the floor plate, and to reduce the height and complex architectural requirements of the tower base. This meant that a concrete structure became possible, with high strength concrete to limit member sizes to acceptable proportions, subject to the construction programme remaining unaffected. The steel and concrete schemes are compared in Fig. 6.

This major revision to the building form was decided upon in August 1989, and detailed design of the reinforced concrete scheme commenced immediately to avoid delaying the construction programme — foundation work had to start on site in October 1989. The manner in which the main contract works would be carried out had been under continual discussion; tender documents had been prepared for the steelwork supply and erection and various forms of management and main contract approaches had been investigated. With a change to a reinforced concrete scheme, the joint developers decided that their two in-house contracting firms, Sanfield and Tat Lee, should form a joint venture, Manloze Ltd., to act as main contractor.

The new scheme

The same basic shape of floor plate was maintained but the area was increased to 2200m^2, thereby reducing the height required to maximize the developable floor area. The design consisted of two principal components: A free-standing 314m high office tower with a mast taking its full height to 374m, and a 30.5m high podium block attached to it. The tower itself comprises three sections: the base — reduced to 30.5m — forming the main entrance and public circulation spaces; the 235.4m tower body containing 57 office floors, a sky lobby and five mechanical plant floors; and the tower top with six mechanical plant floors and a tower mast. Parking is in a three-level basement occupying the full plan area of the site (Fig. 4). By providing clear circulation space at ground floor the owners were able to increase the permitted development plot ratio from 15 to 18, providing a total accountable floor area of 173 000m^2. The overall efficiency of the development measured as net to gross floor area is a remarkable 81%.

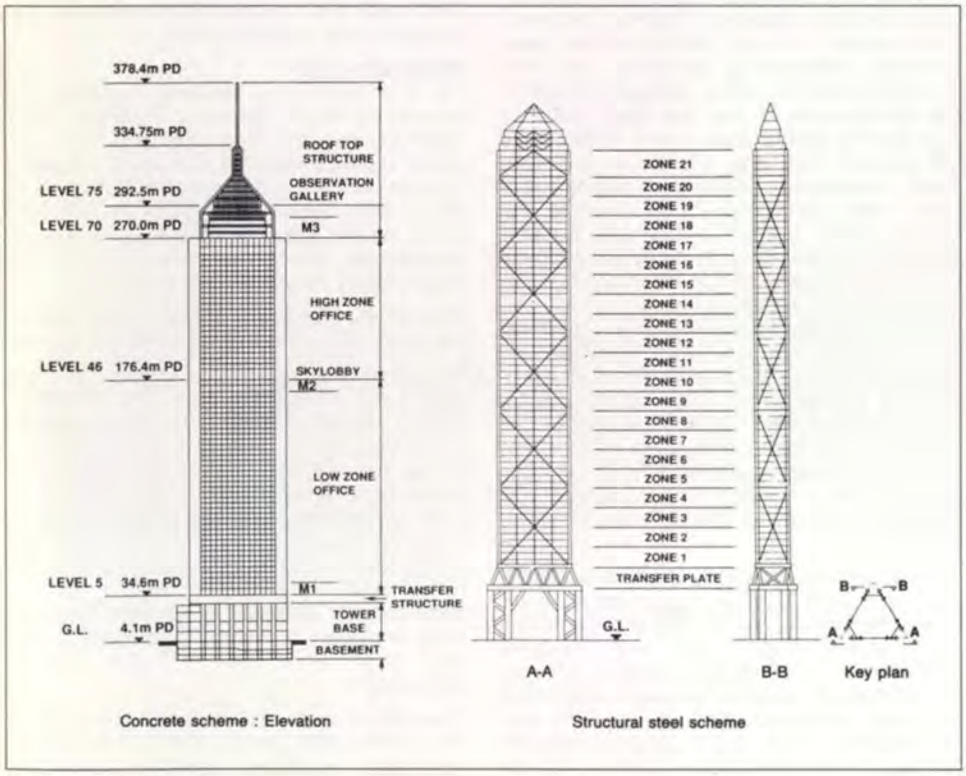
Entry to the building is from ground floor level or through one of three first floor footbridges (Figs. 3 and 5).

These connect the building to the adjoining Convention Centre, a nearby Mass Transit station, and adjacent developments.


3. First floor pedestrian bridge.

4. Site plan.


5. Pedestrian circulation at first floor.



6. The concrete and steel schemes compared.

From first floor level (Fig. 7), occupants are transferred by escalator to the main 12m high entrance lobby on the second floor.

With a population of 8000, vertical transportation is of paramount importance. The 57 office floors are served by seven lift zones, each with four lifts. The four lowest zones commence at the second floor lobby, together with a set of five high speed (8m/s) shuttle lifts. These transfer passengers to the sky lobby at the 46th floor (Fig. 8). From here three further sets of four lifts transfer occupants to the upper zones of the building.

To meet the client's requirement for early occupation, the building was completed in three separate phases, the first up to the 27th floor, the second to the 45th, and the final phase covering the remaining floors above the sky lobby. To enable occupation of the lower portions of the tower whilst construction was still continuing above, building services installations were arranged to match each phase of completion, with a minimal amount of temporary connection work. Separate plantroom floors were provided for each of the building's three phases.

The unusual floor plan resulted in a very small plantroom for the on-floor air handling units (AHUs). The plantroom was not only small but also triangular in shape, making it impossible to incorporate a conventional AHU and discharge silencers within the available space.

After a careful review of the options, it was decided to make use of acoustic AHUs to provide the conditioned air to each floor.

These could be 'made to measure' and designed to conform to the unusual plantroom shape. Being intrinsically quiet, it was also possible to avoid the need for bulky return air silencers. Mock-up tests on site showed that the design would achieve the required noise levels in the office areas and checks on completion showed this to be so.

Substructure

The site is on recently reclaimed land-fill overlying marine clay, alluvial sand and decomposed granite. Bedrock is between 25m and 40m deep and the water table is 2-3m below ground level. The area around the site has had a history of settlement problems, caused mainly by dewatering during the construction of neighbouring developments. A major geotechnical concern was therefore to minimize any further settlement of the surrounding streets, utilities and structures.

In line with the requirements of the initial brief, a site investigation was specified and put in hand. Initial planning assessment indicated that up to four levels of basement of maximum floor area could be required, and the design of a diaphragm wall on this basis was completed in the first week after the site was acquired. The wall was to extend around the whole of the site and be built down to rock, its base pressure-grouted to a depth of 5m below its toe. This preliminary design work allowed construction to begin three months later, after the necessary Building Authority approval processes. By this time it had been decided that only three basement levels would be necessary and the construction drawings were amended accordingly.

The diaphragm wall allowed the basement to be constructed top-down, removing the basement from the critical path and using its floor plates to stabilize the walls during excavation. The diaphragm wall also enabled traditional hand-dug caissons to be used for the foundations without dewatering the ground outside the site to any significant degree.

The foundation design itself was developed with the superstructure design during the six months needed to install the diaphragm walling and grouting work. Once the latter was completed, pumping tests were undertaken, and as some drawdown was still occurring outside the site, recharge wells were placed around the site perimeter.

7. Main entrance lobby, first floor.

8. Sky lobby, 46th floor.

The foundations are large diameter, hand and machine-dug caissons, founded on granite, with a bearing capacity of 5MPa. The maximum column loads of 200MN required caisson base diameters to be as high as 7.4m, with shaft sizes providing adequate space for the construction of the top-down columns from the B3 pilecap level to the underside of the ground floor (Fig. 9). Below the main tower, reinforced concrete columns were used; with steel stanchions beneath the lighter loaded podium. A raft was required under the central core. In order to complete the core up to ground floor level at the same time as the main tower columns, this raft had to be built in open cut excavation. Top-down construction of the core itself could not be achieved without splitting it into a series of discrete elements, and this was not considered advisable. The solution adopted raised the soffit level of the raft from B3 to B2, allowing the pile cap and the core to be constructed within an open bermed excavation. The space below the raft was later used for plantrooms.

The weight of the podium structure is insufficient to prevent the basement from 'floating' under hydrostatic water pressures, so an underslab drainage system was designed consisting of a permeable blanket beneath the B3 slab, in addition to wells penetrating the lower permeability marine clays. This system maintains zero water pressure beneath the slab. It includes piezometers to monitor performance and pressure relief points to ensure that hydraulic pressure cannot occur in the event of a pump failure or pipework clogging. An extreme event check with reduced load and material factors showed that the B3 slab would remain intact even if all pressure relief systems failed.

Superstructure

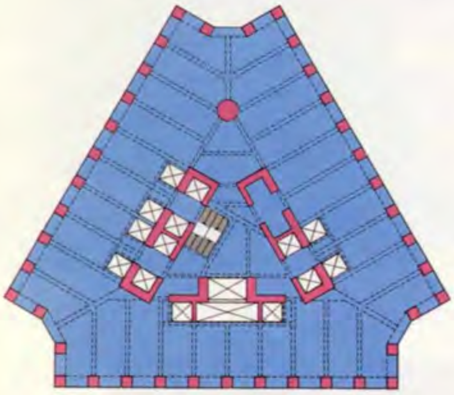
For the reinforced concrete scheme the braced frames in the tower façades of the steelwork scheme were replaced by orthogonal moment-resisting frames of regularly spaced columns and spandrels. The reduced 30.5m tower base, and eased requirements for openness over the lower levels, allowed continuation of alternate columns from the main stability frames to foundation level.

Above the tower base, stability is provided by the tube nature of the external façade frames.

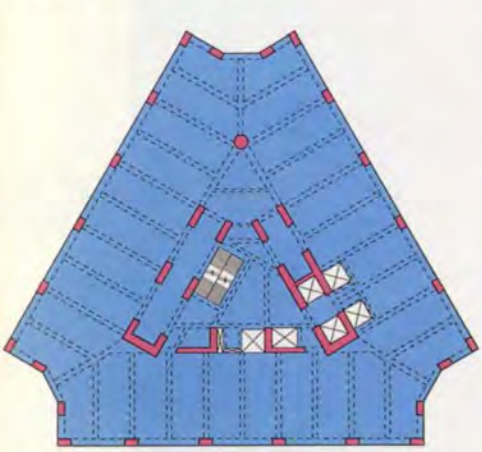
These comprise columns at 4.6m centres and edge beams 1.1m deep (Fig. 10a). The floor-to-floor height is 3.6m with greater heights being provided on the plant room floors and in the 7m high sky lobby. The core has a similar arrangement to the steel scheme, its size and stiffness reducing towards the top of the tower. The core's contribution to the overall stability of the tower above the base is not generally significant, however, below this level; with the reduction in the stiffness of the outer envelope, it serves to transfer the full wind shear acting on the building to the foundations.

The design continued to develop throughout the construction period with further studies eventually enabling alternate perimeter

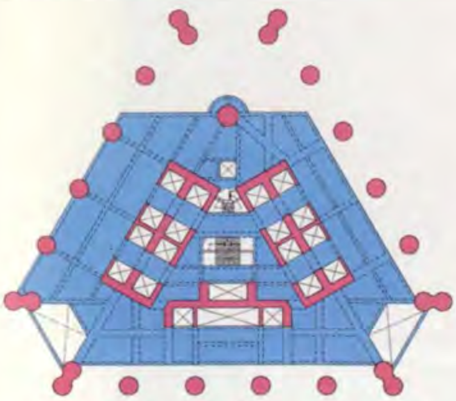
9. Foundations from the air, showing the very large diameter main caissons.



a. Typical plan of lower zone up to Level 26.



b. Typical plan Levels 63-68.



c. Second floor plan, tower base.

10. a to c: Floor plans.

columns to be omitted from the top six levels of the main frame, increasing their spacing to 9.2m (Fig. 10b) and maximizing the benefits to be gained from the spectacular views.

The tower base perimeter transfer beam is 5.5m deep by 2.8m wide, transferring gravity and axial wind loads to the reduced number of columns below (Fig. 10c). The increased column spacing, together with the elimination of spandrel beams over the height of the tower base, results in an increased flexibility of the external frame. The core transfers the full wind shear to the foundations over the lower levels of the building, with a 1m thick slab at the underside of the transfer beam distributing the total wind shear from the external frame into the inner core below.

The wind shear is taken out from the core at the lowest basement level, where it passes to the perimeter diaphragm walls. In order to reduce large shear reversals between the core walls and the perimeter frames in the basement and at the top of the tower base, movement joints are introduced in levels B1 and B2, the ground floor, and the 5th and 6th floors, to separate the two stability systems.

The floor system is similar to that proposed for the steelwork scheme.

Primary beams, typically 700mm deep, span from core to perimeter at 4.6m centres supporting a 150mm thick slab. This system and the perimeter framing was developed in collaboration with the contractor to enable tableform systems to be adopted for the construction of the floor plates.

To ensure that all aspects of the building's performance in strong winds would be acceptable, a detailed wind tunnel study was carried out by Professor Alan Davenport at the Boundary Layer Wind Tunnel at the University of Western Ontario. These tests and subsequent analyses predicted a maximum sway at the 75th floor of approximately 400mm and peak accelerations of less than 20milli-g. The 50-year, three-second gust, gradient wind speed used in the prediction of these figures was 64m/s as required by the Building Authority. Due to the tight design programme the results of the testing could only be used to confirm the performance of the building as a whole, but cladding design was able to take full advantage of the results of the local pressure testing.

High strength concrete

It was essential that a higher strength concrete be used for the vertical structure than that normally permitted for private building works by the Hong Kong Government. Typically, high quality concrete has a 28-day cube strength of 40N/mm^2. The Building Authority limit was 45N/mm^2, but it was decided to seek approval for 60N/mm^2 — considered to be readily achievable using locally available materials. Even higher strengths were contemplated, but these would have needed significant improvements in local standards, quality control, and workmanship: factors that could have jeopardized the construction programme.

Laboratory tests were essential to establish optimum design mix and investigate aggregate characteristics, and were followed by production trial mixes both to establish workability limits and to acquaint suppliers with what was needed before they were asked to tender. The final specification required (among other things) a consistent cement strength, a minimum aggregate 10% fines value, and did not allow water addition to achieve slump requirements. The Building Authority's quality control requirements included taking cube samples from every truck of concrete delivered, and extracting and testing concrete cores from a representative number of structural members.

11. 'Cat-scratch' logo clearly visible at night.

With the columns supporting the tower transfer reaching 2.8m diameter, and the proposed mixes having very high cement contents, temperature effects were considered a major potential problem. Full-size trial columns were cast on site before construction began, and as a result cooling measures were introduced. Even though peak temperatures of over 80°C were experienced, there was little evidence of loss of strength; in general, cube and core strengths exceeded 70N/mm^2 and 60N/mm^2 respectively.

As construction continued, further studies enabled pulverized fuel-ash (PFA) to be used as a cement replacement — previously forbidden in superstructure works by the Building Authority. This reduced heat-gain problems, with the result that the need for cooling could be eliminated from the construction process.

Cladding

Generally, this is a fully unitized system manufactured in Hong Kong and assembled fully glazed on site. The all-glass panels consist of double-glazed units in gold and silver to create the overall façade pattern. An initial concern was the high level of noise from the nearby main roads, but a detailed noise survey and calculations showed that acceptable levels could be achieved in the occupied areas without the need for expensive acoustic glazing. The curtain walling is fitted with double glazing but for thermal rather than acoustic reasons. At night, integral neon lighting units create the characteristic 'cat-scratch' logo for the building over the complete height of the façade (Fig. 11).

Arup Façade Engineering, Sydney, were designers for the glazing and curtain walling of the top floors (70-76), including the pyramid roof glazing and the frame cladding (Fig. 12). The feature frame at the top of the building changed considerably from the original architectural concept, which was wind-tested. A design wind pressure of 6.0kN/m^2 taken from the Hong Kong Regulations was adopted. The sloping glazing consists of a stick system; this has structural silicone glazing seals on the horizontal edges and the glass mechanically restrained by the mullions on the vertical down slope members. The glass panels are double-glazed units, these are approximately 2m x 1.5m, with the outer pane of 6mm heat-strengthened glass and the inner 13.5mm laminated clear glass. The outer pane has a white oven-fired frit applied as discrete horizontal lines; this provides 50% reduction in solar heat but allows external vision at night. The feature frame is clad with PVF$_2$-coated aluminium panels. The space within the feature frame is very confined but nevertheless incorporates a fully drained and pressure-equalized jointing system. A full-scale prototype of part of the sloping glazing and vertical glass wall was tested under simulated wind loading conditions and for water leakage to the Australian SIROWET specification requirements.

Construction

The contractors' input to the development of the design and the planning of the construction work was a significant factor in achieving the speed of construction required. For the basement and tower base, it was accepted that traditional methods of construction were most suitable, although a steel form system was developed for the perimeter columns throughout these levels. Once above the transfer structure, however, a fast cycle was all-important.

Two full floors of steel table forms were purchased to construct the floor system, and broken down into a size which could be easily pushed by workers to their required locations (Fig. 13). Upon striking formwork a table would be wheeled onto one of the external steel platforms erected at each level, from where it would be lifted to the next floor and dropped onto the deck. Perimeter edge forms were fabricated to include safety railings and thus the need for external scaffolding was avoided. Fittings were also provided to ensure that cast-in fixings to receive the curtain walling were accurately positioned within the required tolerances. The column forms were designed to cater for the seven changes in column dimension which were required throughout the height of the tower. 13 sets of steel column forms were used to construct the 36 external columns in each floor.


12. Level 75 observation gallery.


15. Mast installation.

16. right: Completed building.


13. above: Steel table forms for floor system construction.

14. Core construction.

Two sides of each form were made up of smaller modules, one of which was dropped each time the column size was reduced. Forms, including work platforms at the top, could be stripped as a whole from a newly-cast column and placed in a new location over a pre-assembled steel cage within two minutes. Predictions of the effects of columns shortening had been made at the beginning of construction and the contractor was given levels to compensate for these effects. Throughout construction, surveys of shortening effects were undertaken and the previous requirements for compensation were adjusted to reflect the data received.

VSL were appointed by Manloze to provide three specially-designed self-climbing forms to build each of the core segments (Fig. 14), construction generally taking place about six floors ahead of the floor slabs. The forms had to accommodate six changes of lift core configuration, the structural design being modified to ensure that this was reasonably easy to achieve.

The main tower was serviced by two tower cranes and it was important to minimize cranage time for each activity. Making the steel forms easily manoeuvrable helped with this, as did the use of pumps to deliver concrete. This was ready-mixed throughout. Pipelines were installed in liftshafts to three climbing placing bores at the working deck. During the final stages, concrete was being pumped the full height of the tower in one single lift using a Schwing DP8000 concrete pump.

Milestones

The following dates give an indication of the extremely fast construction programme and the major milestones:

site purchase	28 January 1989	3 months
diaphragm walling commenced	April 1989	8 months
design changed to reinforced concrete	September 1989	10 months
foundations commenced	November 1989	14 months
foundations completed	March 1990	17 months
ground floor slab completed	June 1990	21 months
tower base completed	October 1990	33 months
temporary occupation permit granted for lowest 27 floors	October 1991	36 months
first tenants move in	January 1992	
temporary occupation permit granted for lowest 45 floors	February 1992	37 months
topping-out of tower	April 1992	39 months
jacking of mast	June 1992	41 months
full occupation permit	December 1992	47 months

The final element to be completed was the steel mast, rising 64m above the apex of the roof. It is supported by the central core and stabilized by a concrete vierendeel frame extending 16m above the rooftop. The mast has a maximum diameter at its base of 1.6m and a wall thickness of 40mm, and was lifted to the top in sections and fabricated inside a liftshaft within the core directly below its final location (Fig. 15). Once fabrication and painting had been completed it was jacked into its final position during three days.

Conclusion

Most high-rise development in Hong Kong has historically been based on the use of reinforced concrete, and building contractors there have always been among the fastest in the world at erecting such structures. Central Plaza is a prime example of the construction speeds which can be achieved with sensible planning from the commencement of the design. The most enduring memory for all of those who were involved in its completion will be how the development of extremely close working relationships between the developer, his designers and the contractor enabled the remarkably fast programme to be achieved. Despite a very short design lead time and the late decision to change to reinforced concrete, a four-day construction cycle for the typical floors was achieved, equalling that predicted for the structural steel scheme. Superstructure from ground floor to the base of the mast was completed in only 20 months.

Central Plaza is now the fourth tallest building in the world (after Chicago's Sears Tower, and the World Trade Centre and the Empire State Building in New York), and the tallest constructed of reinforced concrete.

References

(1) AYRES, P.G. *and* MACARTHUR, J.M. The structural engineering design of Central Plaza, Hong Kong. *The Structural Engineer*, *71*(11), pp.185-191, 1 June 1993.

(2) MACARTHUR, J.M. *and* READ, A.S. An approach to the development of high strength concrete in Hong Kong. Hong Kong Concrete Technology and Construction Conference, November 1990. Hong Kong Institution of Engineers.

Credits

Client:
Joint venture of Sun Hung Kai Properties Ltd., Sino Land Co.Ltd., Ryoden Property Development Co.Ltd.
Architect:
Ng Chun Man & Associates
Structural engineer:
Ove Arup & Partners
The authors gratefully acknowledge the efforts made by all the staff, too numerous to mention individually, who were involved on the design and supervision of this project.
Building services:
Associated Consulting Engineers
Acoustic consultant:
Arup Acoustics
Cladding consultant for tower top:
Arup Façade Engineering
Quantity surveyor:
Levett & Bailey
Contracting joint venture:
Manloze Ltd.

Photos and illustrations:
1, 3, 7, 8, 11, 12, 16: Colin Wade;
2, 6, 10: Ove Arup & Partners;
4, 5: Ng Chun Man & Associates;
9: Alan Spalding;
13, 14: K.T. Heng; 15: VSL Ltd.

1

'Japan Bridge', Paris

Kate Purver
Pat Dallard

Introduction

The 100m span 'Japan Bridge' footbridge was a project begun by Peter Rice and completed by his Paris company, RFR. Arups assisted with the engineering design, and in particular with the computer analyses of the steel structure. The bridge was opened in May 1993.

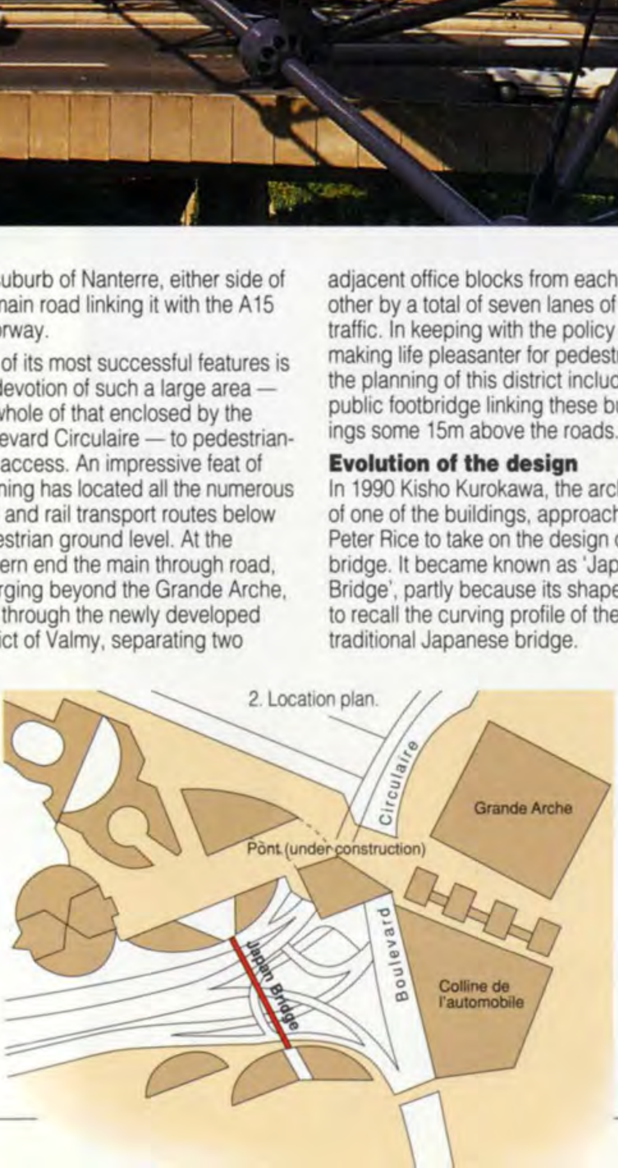
The site

La Défense, the business and financial district outside Paris, continues to grow, both in size and prestige. Despite the recession, several major new developments have recently been completed, with more under construction and planned. Having overspilled its original boundary, the Boulevard Circulaire, La Défense is now expanding westward, towards the suburb of Nanterre, either side of the main road linking it with the A15 motorway.

One of its most successful features is the devotion of such a large area — the whole of that enclosed by the Boulevard Circulaire — to pedestrian-only access. An impressive feat of planning has located all the numerous road and rail transport routes below pedestrian ground level. At the western end the main through road, emerging beyond the Grande Arche, cuts through the newly developed district of Valmy, separating two adjacent office blocks from each other by a total of seven lanes of traffic. In keeping with the policy of making life pleasanter for pedestrians, the planning of this district included a public footbridge linking these buildings some 15m above the roads.

Evolution of the design

In 1990 Kisho Kurokawa, the architect of one of the buildings, approached Peter Rice to take on the design of the bridge. It became known as 'Japan Bridge', partly because its shape was to recall the curving profile of the traditional Japanese bridge.


2. Location plan.

The architect had envisaged a low arching tube which would carry the pedestrian walkway, itself covered by a triangular glazed enclosure. However, the supporting buildings' inability to take significant horizontal load led to a tied-arch solution. Consideration of the torsion resulting from lateral wind load on the walkway glazing led also to the introduction of the double arch: two bowstring arches leaning together, forming a 3D structure stable against lateral load and also echoing the triangular shape appearing on the architect's first sketches.

The separation of the walkway from the tendon allowed visual emphasis of the tied-arch principle. The walkway is supported on braced struts which spring from the tendons. The latter, visually unencumbered by the deck, appear as the tension elements they are.

Analysis and behaviour

To reduce bending in the arches, their shape was chosen to be as nearly as possible funicular to the self-weight of the bridge. The tendons follow the same curve at a lower amplitude.

The façades of the supporting buildings are not parallel, and the architectural wish for visual coherence led therefore to an asymmetrical design, with one arch longer than the other. The angle between the hanger planes and the axis changes gradually from one end of the bridge to the other. This decision was taken early on in the project, with the result that no two elements have the same length, nor two connections the same angle. Computers were thus essential for the generation of the geometry, for analysis, and for fabrication.

With the funicular arches, analysis showed the bridge to be highly stable under vertical load. Vertical behaviour is simplified by the absence of continuous longitudinal bracing between the tendon and the deck elements. This minimizes the tendency for these two to form a vertical beam, which would result in the deck taking part of the tendon force. The deck is stabilized along the axis of the bridge by a single central braced bay.

Lateral load is shared by several mechanisms: beam action of the tendon plane, differential action of the two arch-tendon planes, and arch bending. Lateral wind loading is the critical loadcase for the stability of the bridge. As wind load increases, the load in the upwind arch and tendon decreases, until at a certain load factor this would de-stress the hangers between arch and tendon. The stabilizing of the arch by the two sets of hangers in tension is lost, and the arch is free to buckle. Considerable work was needed to investigate this effect and ensure a sufficient factor of safety against buckling in this and other lateral modes.

Tendon and node detailing

The tendons are 200mm solid high yield steel, carrying 6000kN tension under extreme load. The principal nodes, at around 4m spacing, also form the connection point between the hangers, deck support struts, and horizontal bracing struts. The angles between each of these elements are different at every node.

The node detail had therefore to accommodate this varying geometry and to transfer the tendon force, while avoiding any detailing (such as welds or angle changes) which could act as crack initiation points for fatigue or brittle fracture. Due to the large steel thicknesses and high tension, brittle fracture became a particular concern.

The final detail involved threading the bars into the nodes, with a machined 'unloading throat' incorporated just before the thread to minimize stress concentrations at the first thread. The nodes were made from forged 'demi-nodes', connected with prestressed bolts. This solution also facilitated erection; the tendons were brought to site with demi-nodes already threaded to the ends of each bar, and bolted together in situ.

3. Transporting the central section of the arches.

4. French regulations require a full-scale load test for any public bridge.

Construction

The density of roads beneath the bridge made the provision of any permanent cranage impractical. Instead, the contractor erected a temporary scaffolding bridge on two intermediate towers to form a working platform. Elements were unloaded during night possessions and erected using a gantry trolley running on rails along the platform.

The arches, which are welded triangular hollow sections of 30-55mm thick plate, were fabricated in five parts — the central section and the four 'legs'. Transport of each by road from Epinal, in eastern France, to Paris, took around two weeks. The longest, central, section weighed 50 tonnes and formed a load 50m long. Each was erected using two crawler cranes in a night lift, onto temporary supports on the two platform towers, and the splices site-welded.

Once the arches were in place, the contractor erected the tendon and deck structure progressively from one end of the bridge. During construction, therefore, the arches worked in bending as a three-span beam between the temporary towers. Once all elements were in place, these support points were jacked up so that the arch feet moved inwards sufficiently to allow the final arch-tendon connection to be made. Finally, de-jacking left the bridge free-standing.

Credits

Client:
SARI Construction representing SCI Puteaux Kupka
Project management:
SARI Ingenierie
Concept architect:
Kisho Kurokawa
Consulting engineers:
RFR with Ove Arup & Partners
Contractor:
Viry SA
Photos and illustrations:
1, 7: Ana Maksimiuk;
2: Trevor Slydel;
3, 6: Viry SA; 4, 5: Kate Purver

▲ 5. Underside of bridge, showing nodes and struts. ▼ 6. Welding attachments to node.

7. Inside the completed bridge.

Printed in England by Reedprint Limited, Windsor, Berkshire