THE ARUP JOURNAL

50TH ANNIVERSARY ISSUE 1/1996

THE ARUP JOURNAL

Vol. 31 No.1
1/1996

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

Tel: 0171 636 1531
Fax: 0171 580 3924

Editor: David J. Brown
Art Editor:
Desmond Wyeth FCSD
Deputy Editor:
Hélène Murphy
Editorial:
Tel: 0171 465 3828
Fax: 0171 465 3716

Front cover:
Edinburgh International Conference Centre
(Photo: Harvey Wood)

Back cover:
Nynex Arena, Manchester
(Photo: Ian Lawson)

Eurostar train image: Trevor Slydel

Editorial

On 1 April 1946 Ove Arup - at an age when many are already considering retirement - withdrew from the two commercial businesses of which he was then a member, and 'went it alone' as an independent consulting engineer. Thus began the firm that has evolved into the worldwide family of practices that bear his name.

In 1995 the centenary of Ove's birth was celebrated and now, one year on, the many parts of Arups look forward on the 50th anniversary of their founding.

'Ove N Arup Consulting Engineer' - which became Ove Arup & Partners in 1948 - opened offices simultaneously in London and Dublin, so it is fitting that this, the first of two celebratory issues of *The Arup Journal*, should be devoted entirely to current projects in the UK and the Republic of Ireland. Issue 2/96 will concentrate on work in some of the many other countries where Arups now practise.

Arups' growth has not only been in numbers and geographical spread, but - crucially - in the range of professional disciplines which operate in the firm. Originally confined to structural design of buildings, it has progressively embraced other areas of building engineering and civil and industrial engineering, as well as R&D, transportation, acoustics, planning, fire, seismic, communications, environmental, project management, and other services. All of these both work directly for external clients, and support each other and the traditional building disciplines in the mutual environment that has become known as 'seamless Arups'.

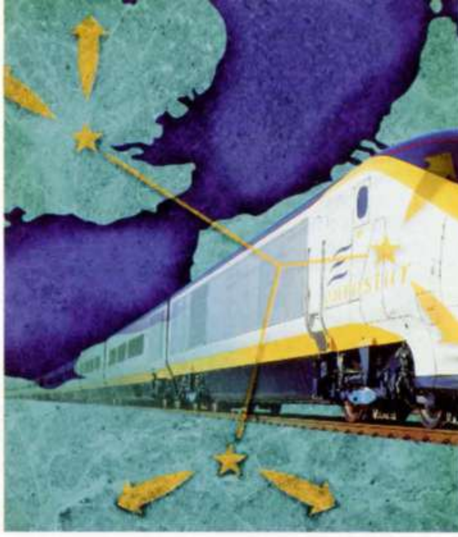
Thus in most of the projects described in this edition, however much they vary in scale and differ in type, the 'core team' has been assisted to varying extents by specialists from elsewhere in the firm: building services engineers by fire engineers and acousticians; structural engineers by experts in historical aspects of materials; transportation engineers by environmentalists, economists, and planners; and so on. This kind of inter-disciplinary assistance and cross-fertilisation is not merely confined to UK and Irish projects of the kind described here. That they are now available across the firm worldwide is one of its greatest strengths.

Since its inception, also, Arups has been noted for innovative engineering, and increasingly for taking an assertive and pro-active role in areas outside the usual territory of a consulting engineering practice. On 29 February 1996 the Secretary of State for Transport announced that London & Continental Railways had been successful in its bid to design, construct, and operate the High Speed Rail Link from London to the Channel Tunnel.

This success is a triumph for Arups. It is eight years since the firm started work on CTRL - first investigating alternatives to British Rail's proposed route, which seemed to be unsatisfactory from many points of view, and then identifying and lobbying for the route it thought best, entering London from the east via North Kent and Stratford.

Since winning the route argument in 1991, the firm has been working with BR on the planning, engineering design and consents procedure for the CTRL, as described on the following pages.

Now, as a member of the consortium that is going to design, build, and operate the Link, Arups has in its 50th anniversary year secured one of the most significant design opportunities of the 20th century.



Planning high speed railways into Europe: an update

David Loosemore

Neil Shepherd

Introduction

Arups have been involved in the Channel Tunnel Rail Link (CTRL) since 1988. Various disciplines within the Partnership have been concerned, ranging from an engineering design team and town planning staff seconded to the project, to specialist consultancy advice on environmental and design matters. Since 1992, an engineering design team has worked within Union Railways Ltd (URL) in Croydon, with responsibility for a 28km section of route between Barking, through Havering, Thurrock, Dartford, and into Gravesham.

The character of the area through which this section of the route passes is diverse, made up of a range of industry including the Ford motor works at Dagenham, agricultural land, residential areas, marshland, and the Thames. The area is subject to development pressures, such as the Barking Reach project currently under construction, and other strategically important schemes at Rainham and Ebbsfleet. This diversity, as well as the need to respect major environmental constraints, such as Sites of Special Scientific Interest, presented major challenges to the engineering team.

In addition, Arup town planning specialists have been seconded to Union Rail in key roles associated with route selection, safeguarding, and Bill preparation for the entire length of the route. Staff from Arup Economics & Planning, Arup Acoustics, and Arup Environmental have also provided specialist advice as part of the Environmental Assessment work, as well as contributing to the full scheme design of the route.

This article describes the key inputs of these groups at different stages of the project, and updates a previous article on the CTRL.

'Safeguarding' the high speed route

The proposed CTRL route was reported to Government in October 1993. The decision on the route to be safeguarded under planning legislation was announced on 24 January 1994, apart from sections at Ashford and Pepper Hill in Gravesham.

The safeguarding process protects it from encroachment by other developments, and forces all planning applications, whether partly or wholly in the 'safeguarded zone', to be referred to URL for consideration. Arup planning staff have been assisting in the implementation of this process.

Concerning Pepper Hill, Government asked for further work, and the Arup team re-examined three rail alignments under and around it which had previously been included in the report to Government in March 1993. The selected route, a shallow bored tunnel under the housing estate (Fig.1), was disliked so much by local residents that they formed an action group and embarked on a major lobbying campaign of the local MP and councillors, which undoubtedly influenced Government's decision for a re-examination. The choice was between the tunnel and either a high-level dominant viaduct across the heavily-trafficked A2 trunk road round the estate, or a cut-and-cover tunnel under the A2 on the same horizontal alignment as the viaduct. After further development, including many presentations to and extensive consultations with all parties, a comparative report was prepared in March 1994. On 28 April 1994 Roger Freeman, then Minister for Public Transport, confirmed the cut-and-cover tunnel as Government's chosen option.

Together with Ashford, both sections were confirmed by June 1994. The whole route was now safeguarded.

1. Pepper Hill: This superimposition shows the final route (left) in a cut-and-cover tunnel under the A2/B2175 intersection. The green line (right) shows the original alignment under the housing estate.

Preparation of the CTRL Bill

Authority to build the CTRL will be given by an Act of Parliament, which started its process through both Houses as the CTRL Bill. Preparation of drawings and documents to support the Bill began in spring 1994. The drawings differ from conventional engineering drawings in that only the centrelines of proposed rail and road crossings are shown, together with the Limits of Deviation (LODs) and Limits of Land to be Acquired or Used (LLAUs). The LODs, both vertically and horizontally, define the maximum permitted tolerances from that alignment. They define the limits for compulsory acquisition of land required for the construction and operation of the railway, roads, etc, whereas LLAUs relate to the powers proposed for the maximum extent of compulsory acquisition of land, or of rights in land, required for temporary and permanent works for a specified ancillary purpose, such as construction sites.

Addressing environmental concerns has always been integral to the project and developing the design has therefore involved close integration of environmental and engineering design objectives. The process has aimed from the outset to take full account of environmental effects from constructing and operating the new line, and to incorporate appropriate mitigation measures like noise barriers and landscaping as the design evolved. Arup Environmental and Arup Economics & Planning have contributed to design of the mitigation and assessment of the environmental effects.

The CTRL will be designed to the anticipated environmental standards for new infrastructure projects beyond 2000. With this in mind, a Code of Construction Practice (COCP) is being developed in discussion with relevant local authorities. More immediately a detailed statement of the environmental effects of the CTRL, the Environmental Statement (ES), was submitted with the Parliamentary Bill. Arups contributed to the ES by providing the Environmental Specialist Reports on atmospheric effects, planning effects and construction noise.

Parliament's consideration of the Bill

On 23 November 1994 the CTRL Bill was introduced to the Commons, and copies, plus plans and sections of the intended works as well as the ES, were available to the public. On 16 January 1995 the Bill had its Commons Second Reading, when MPs decided that the proposed scheme of works should be approved in principle; this triggered the start of petitions against the Bill with latest deposition dates of 6 February 1995, for individual petitioners, and 30 January 1995 for others. Petitions, 993 in all, were submitted by individuals, groups, and organisations on matters where the Bill would affect directly special interests (rather than general concerns) and who sought protection to eliminate or minimise anticipated adverse effects. Some were deposited in person, others by MPs or by registered Parliamentary Agents. In all cases the fee was £20 payable on presentation. Petitioners employing professional advisers like Parliamentary Agents or counsel had to pay their fees.

Arup staff have had extensive involvement in URL's consultation process, which formed the basis of discussions with petitioners. A programme to prepare rebuttals and responses was co-ordinated from all disciplines, addressing the advantages and disadvantages of each aspect of the route petitioned. Often this involved comparison with the petitioners' options, which in most cases had to be brought up to a similar level of design. A Select Committee of nine MPs, appointed to consider the deposited petitions, met for the first time on 21 February 1995 in the historic surroundings of the Grand Committee Room.

The procedure before a Select Committee is broadly similar to a public inquiry, except that evidence is given on oath. Only one speech can be made for a petitioner's case and this may be either before or after any backing evidence. Witnesses may be cross-examined. When a petitioner's case has been put, any appropriate response is given. If witnesses are called for by Government in response to a petitioner's case, that petitioner has the right to cross-examine and speak again to the Committee briefly by way of reply. Committee meetings are open to the public and a verbatim record is kept. During this Committee Stage a few petitioners decided to withdraw, either as a result of more negotiations sufficient to allay particular concerns, or from further discussions with the petitioner to clarify uncertainties. In other cases petitioners deferred to a later date, so as to have more time to negotiate with URL.

By the Summer Recess on 20 July 1995, and after 54 days of sittings, the Committee recommended in principle certain changes to the Bill, which were considered by John Watts, Minister for Railways and Roads. On 29 September 1995 Government announced its acceptance of most of the Committee's recommendations, and offered alternative proposals to meet the remainder.

Parliament's consideration of Additional Provisions

The Select Committee now had to consider these changes, and alternative proposals, in detail. First, additional 'parliamentary documents' (Additional Provisions) had to be deposited, and notices served on those who would be affected directly by the proposed changes. Such persons could, by petition against that amendment, seek to present their views to the Committee as before. These Additional Provisions were deposited to the Select Committee on 7 November 1995; the petitioning period expired on 6 December 1995.

Mardyke Additional Provision

One such Additional Provision occurred in the section of route in Thurrock. Arups had developed several route options and presented them to Government in October 1993. The basic proposal here was for a viaduct close to the Mardyke Park housing estate, Purfleet (Fig. 2). This became the safeguarded route announced by Government on 24 January 1994. However, during early consultation with residents and the local authority, another option had emerged whereby the railway would be aligned further north of the estate and at ground level. This 'low level' option would cost £13M more.

The Select Committee accepted the petitioner's arguments that the original proposed viaduct would be visually and aurally intrusive, and recommended that the CTRL incorporate the 'low level' alternative. It was once again worked up in consultation with Essex County Council and Thurrock Borough Council. With the Additional Provision the CTRL will now cross the existing railway on a viaduct 1km west of the housing estate. The new railway will continue eastwards on the north side of the existing London, Tilbury & Southern Railway (LT&S), and then run close to the A13 and Purfleet Bypass.

A bridge will replace a level crossing. The CTRL will be at approximately the same level as the existing LT&S railway as it passes the estate, but about 80m from the nearest houses rather than the 30m of the original viaduct alignment.

The Select Committee reconvened to consider 16 petitions, 11 of which relate to the Mardyke Park 'low level' option. Interestingly enough, but perhaps not surprisingly, one petition received was for rather than against the Mardyke Park Additional Provision. The petitioner was Thurrock Borough Council and Essex Country Council who successfully petitioned for the change in alignment during the first Select Committee Stage.

2. Mardyke Park, Purfleet: Graphic superimposition of the final route. At ground level, it passes 50m further from the houses than the original viaduct (parallel green line to the left).

Chronology

October 1993
URL Report to Government of 'Refined Route', including appraisals of options and mitigation measures proposed as a result of environmental and engineering development and consultation.

24 January 1994
Government announcement of Route except for Pepper Hill and Ashford sections, which were to be subject to further consultation and comparative appraisal. Confirmation of St. Pancras as London Terminus. Route safeguarded under planning legislation on 24 February 1994.

Consultation
From March-October 1993 and January-March 1994 this involved :
- 100 formal consultation meetings and 55 informal meetings with councils or local consultation groups
- 650 other meetings with specialist interest groups, professional bodies, and individuals.
- 94 information centres, attracting 23 000 visitors.

April 1994
Nine Bids received by DOT to prequalify for competition to select private sector promoter to design, build, finance, and operate the CTRL.

28 April 1994
Government announcement of preferred routes at Pepper Hill and Ashford confirmed and safeguarded.

Spring 1994
Start of preparation of drawings and documents in support of Parliamentary Bill.

July 1994
Appointment of Dr Brian Mawhinney as Secretary of State for Transport.

31 August 1994
Government announcement by Dr Mawhinney that an intermediate international and domestic station would be located at Ebbsfleet. The option of a station at Stratford would be kept open.

31 August 1994
Government launch of competition to select private sector consortium to deliver and operate CTRL. Issue of bid documents to four pre-qualified groups (with original members):
- Green Arrow (Hochtief, Costain, Nishimatsu, Siemens)
- Eurorail (BICC, GEC, HSBC Holdings, National Westminster Bank, Seeboard, Trafalgar House)
- London and Continental (Arups, Bechtel, Blue Circle, Halcrow, National Express, Virgin, Warburg)
- Union Link (AEG, WS Atkins, Holzmann, Mowlem, Spie Batignolles, Taylor Woodrow).

23 November 1994
CTRL Bill introduced into the House of Commons as a Hybrid Bill to authorise construction, operation and maintenance of the CTRL.

16 January 1995
Second Reading of the CTRL Bill.

21 February 1995
First sitting of the House of Commons Select Committee on the CTRL Bill. Chaired by Sir Anthony Durant, it comprised five Conservative and four Labour members.

14 March 1995
Bids received from four consortia.

1 April 1995
Transfer of ownership of Union Railways Ltd from British Railways Board to the Department of Transport.

3 July 1995
Government announcement by Secretary of State for Transport that Eurorail CTRL Ltd. and London and Continental Railways will go forward to the final stage of the CTRL competition.

5 July 1995
Appointment of Sir George Young as Secretary of State for Transport.

20 July 1995
Select Committee announces initial recommendations about the CTRL, having dealt with 993 petitions and sitting for 54 days.

29 September 1995
Government announces acceptance of most of the Select Committee's recommendations, and offers alternative proposals to meet the remainder; add itional provisions required for six of the recommendations, at St Pancras, Barking extended portal, Rainham services diversions, realignment at Mardyke, Ebbsfleet-Northfleet passenger connection, and a road scheme at Ashford.

November-December 1995
Staged deposit for Additional Provisions to the CTRL Bill. Continuation of Select Committee hearing deferred petitions against the November 1994 deposit and some of the November 1995 Additional Provisions deposits.

15 December 1995
Announcement date for competition winner postponed, to allow further time for revised bids submitted on 15 December 1995.

31 January 1996
Select Committee announced its decisions for consideration by the Department of Transport with the expectation that Government would provide its response by 14 February 1996.

29 February 1996
London and Continental announced as winners of the competition.

PARLIAMENTARY STAGES FOR A HYBRID BILL

Introduction and First Reading:
Formalities; no debate.

Second Reading:
Debate in the House on principles and powers being sought. Amendments not made at this stage. Arrangements for Select Committee and closing date for petitions are settled at this stage.

Petitioning Time Expires

Select Committee Stages:
Committee considers petitions from people whose private interests are specially affected by the Bill. It may recommend amendments to the Bill in the light of petitions.

Standing Committee:
Committee considers the content of the Bill clause-by-clause as amended by the Select Committee.

Report Stage:
The Bill, as amended in Standing Committee, is brought again before the whole House of Commons. Further amendments may be proposed and agreed.

Third Reading:
The House debates whether the Bill should be passed as amended. If so, it goes to the House of Lords. NB: Report and Third Reading normally takes place on the same day.

House of Lords:
The Bill goes through the same procedural stages as in the Commons; amendments can be made at Report Stage but in the Lords they can also be made at Third Reading which is taken on a separate day.

After Third Reading in the Lords, the Bill is referred back to the Commons for consideration of amendments made in the Lords.

Royal Assent:
If the Commons and Lords both pass the Bill it receives Royal Assent and becomes an Act of Parliament.

Other work in advance of Royal Assent

The detailed design of the CTRL may not be finalised until shortly before each stage of construction commences. This is standard practice for such major engineering projects. However, because of the Government's committed timetable for the proposed 2003 opening, it is necessary to undertake some works in advance of Royal Assent to prepare for construction of the CTRL. Geotechnical investigations to establish ground conditions along the route, and preliminary archaeological investigations have also been made. It has also been necessary to plan, and in some cases design, utility diversions because of the long lead times.

The Rail Link bid competition

At the same time that authority to build the CTRL was being sought from Parliament, consortia were tendering for its financing, design, construction, and operation. Four major international consortia prequalified to tender, and on 3 July 1995 the shortlist was narrowed to two: Eurorail CTRL Ltd, and London & Continental Railways (of which Arups are a founder member).

The selected tenderer is designated as the CTRL 'nominated undertaker' for the purposes of the Bill when enacted, and will thereby be able to exercise the powers of the Bill to build a railway. They will have flexibility in specifying and designing the scheme. Any variation to the design must be within the lands defined in the Bill and in addition should not materially worsen the environmental effect compared to the assessment presented in the ES.

The winner owns Union Railways and European Passenger Services (EPS), both formerly part of British Rail. Union Railways has worked on the planning and development of the CTRL, while EPS operates the Eurostar services through the Channel Tunnel between London Waterloo and Paris/Brussels, jointly with French and Belgian railways.

The decision on the preferred bidder was expected before Christmas 1995 but was finally announced on 29 February 1996.

Reference

(1) BOSTOCK, M *et al.* Planning high speed railways into Europe. *The Arup Journal, 28*(4), pp.3-7, 4/1993.

Credits

Client:
Union Railways Ltd

Consultants:
Ove Arup & Partners Louise Conroy, Colin English, Chris Manning, Andy Officer, Joan Watson, Liz Williams (acoustics)

Robert Abernethy, David Anderson, Paul Barlow, Peter Brooke, John Burrows, Brian Coyle, Brian Dunlop, Steve Dyson, Richard Foster, Alistair Giffen, Bob Goldsbrough, Simon Harris, John Henry, Terry Hill, Stella Job, Phineas Keane, David Kelly, Peter Knight, John Lambert, David Lewin, David Loosemore, Jason Manning, Chris Nobbs, Nick Rabin, John Redding, Peter Richardson, Robin Riddall, Corey Russell, John Seaman, John Shaw, Neil Shepherd, Nick Sidhu, Angus Stephen, John Stowell, Paul Thompson, Colin Wilson (engineering)

Sue Blanch, Jo Bole, Ingrid Byng, Robert Campbell, Linda Dewar, Julian Hart, Neil Jenkins, Paul Johnson, Venessa Lam, Niall Lloyd, Robert Paris, Steve Seymour-Jones, Andy Talbot, Lorna Walker (environmental)

Lorna Andrews, Claire Beedle, Mark Bostock, Maggie Gatland, Adrian Gurney, David Joy, Mark Smith, Jim Strike, Corinne Swain, David Wickens, Ray Willis (planning)

Tim Frost, Annie Gavin Adamson, John Gilbert, Helen Palin, Caroline Powell (support)

Illustrations:
Photos: Union Railways; *logo and graphic superimpositions:* Nigel Whale.

The Private Finance Initiative: a personal view

Duncan Michael

Introduction
The British government launched its Private Finance Initiative in 1992 with the stated aim of increasing the private sector's involvement in the provision of public services. It appointed a panel of experts chaired by Sir Alastair Morton to advise government on how to implement the initiative successfully. Government subsequently made Sir Christopher Bland chairman of the panel and relaunched the Initiative in 1995. Privatising the ownership of enterprises and contracting out the provision of services are Government policies with similar aims[1]. Since most of Arups' work is about capital projects we must adapt our ways to the manner in which so many new projects are being set up. This note is a look and think exercise. The views in it are the author's; he hopes they will help to focus and direct our role.

The public/private interface
In Britain just about all finance is private until it becomes public, with the exception of money from government/Crown-owned assets like mineral rights, broadcasting rights, and the Post Office. Government gets most of its money from private sources via duties, taxes, fines, fees, and contributions. Usually this is not enough to pay for its spending and it turns for loans to further private sources - pensioners with its Granny Bonds, children with its Savings Certificates, gamblers with its Premium Bonds, and the City for larger quantities of money at higher rates.

Some services and projects feel like public sector naturals, including law courts, prisons, schools, the Øresund crossing, and the Channel Tunnel. A premise of current thinking by government and by academics and writers, said and written clearly, is that the public sector is in its nature less competent at operating anything than the private sector. If you believe this, you will tend to find evidence for it. If you have power, your own actions and reactions will make it a self-realising opinion. And so here we are.

The counterpointing of public and private has its uses, but when stretched even a little beyond these uses it is worse than neutrally useless: it becomes pernicious by being misleading. At present we are being urged to admire the economic tigers as the route to better economic performance. For the tiger which is Hong Kong its government has arranged for *public* ownership of the railway corporations, the airports, the land, the water industry, and 50% of all new housing, and has very few plans to alter that ownership pattern. In Britain most of today's public services were originally created because of unacceptable deficiencies, both social and economic, in private sector provision. It is nonetheless entirely proper to reconsider all these earlier decisions periodically to see where the balance of interest and competence has shifted enough to merit changing existing arrangements.

Capital pursues likely success and not vice versa. There is a large supply of funds (not least our own pension funds) looking for safe and profitable long-term placing. All that supply of capital sees a dearth of worthwhile opportunity. People - individual people - are often the key to success and certainly to comparative success. How to infuse public sector enterprises with this people factor is a complex issue, given our society's deep inhibitions. Nonetheless for projects like those under the PFI at least one serious champion is essential, namely the entrepreneur, and success is made more achievable if the public side has an equivalent champion, arranging the concession.

Many PFI schemes will take the form of a franchise containing some duties and some protections for the franchise receiver. This necessarily reduces the scope for subsequent innovation or competition; Eurotunnel, for example, has sole right to build the next crossing between England and France through much of the 21st century. It may seem like a joke today, but it could be the jewel in Eurotunnel's hat one day.

Much of the scene-setting for PFI has been focused on risk and its transfer: a factor, of course, but the sad 'cup-half-empty' point of view. It allows government to sound tough, as it appears to stick risk onto the private company. The administration of awarding PFI projects seems also to be getting done in an overly involved way, as if mother does not want to let the children leave. In a publicly-financed project these administrators would have the chance to steer as events unfolded. In the new situation the whole journey gets a dummy run before the start, like negotiating the course of a football match before going on the pitch. Reality just is not like that, and problems will get solved or opportunities taken in the context, at the time. Even the most disastrous project has to deal with only a fraction of the risks that would be listed in a formal risk analysis.

These preoccupations are fair if you assume that the private sector tends to have crooks and charlatans, but are not consistent with the concept of the private sector as the shining knight of wealth creation. Much more important to success than the risk issue is to ensure the creation of a reasonable chance of reward within the deal. To focus on avoiding losing makes it more likely that winning gets largely forgotten about.

Although release of innovation is put forward as a consequence and benefit from PFI, Arups' experience is that reliability is a much more prized quality than technical innovation or invention. For income stream, for long-life responsibility, and for the climb out of debt, small operating advantages from leading-edge technology have very little attraction compared with reliability; privately-financed projects put a premium on innovations in funding, ownership, team formation, and leadership.

1. Eland House, Westminster, London SW1 (Photo: Paul Raftery)

One nice paradox highlighted at present is the huge dependency on the public sector of the British construction contracting industry, which has held itself out as the apotheosis of the ethos of private enterprise. It now finds itself driven to becoming the part-owner of roads, railways, bridges, airports, hospitals, and prisons in order to get work for its construction divisions. An inversion of the private/public interface is the Housing Corporation, which uses public money to fund private providers of new social housing in Britain. These providers are typically not-for-profit firms or charities. This is a *Public* Finance Initiative. Local government authorities could be an attractive vehicle for projects and their finance, an area where the public/private interface is easily moveable.

One of the good aspects of the USA is the self-aware participation of people in public decisions, such as the vote by a city's citizens on borrowing large sums from private sources to build a new city library. All these assertions have been simply to make the case that almost everything in a country has a public and a private face. It follows that to try to differentiate things on this basis or to use it as an operating tool is doomed to be very frustrating. It is fighting against nature. It was John Kenneth Galbraith, I think, who pointed out that if a nurse in a state hospital gets overtime for extra hours looking after your grandmother the economy gets poorer; if that same nurse does so in a private hospital the economy grows; and if you do the extra nursing yourself the economy does not even notice. He did not feel the need to pursue the fault line on to a nurse from a private company working in a public hospital or a volunteer working in a private hospital. His ideas were formed in sunnier times.

Cases
Case histories help to test the claims made here. Let us start with Eland House, an office building of some 30 000m^2 funded by a private promoter (Land Securities) and recently rented for many years ahead by a public user (Department of the Environment) with all sorts of risks spread to one party or the other. That public user is vacating a publicly-owned building. It is an exact fit to the PFI in that it increases the involvement of the private sector in the provision of public services. For whatever reason it has not been promoted as such, not yet anyway. Let us compare the Skye bridge with the Dartford bridge. The engineering

1. These definitions have been taken from the Treasury document 'Private Opportunity, Public Benefit', November 1995.

tasks were about equal in terms of width of water to be crossed, ancient navigational demands, and provision of access roads. The differences in width, in winds, in remoteness, and in access about balance out. They were both created as private sector franchises too early to be fruit of the PFI launch. The one will be carrying only 1% of the traffic of the other, but they should both succeed financially. In the case of the Dartford bridge, it is actually a small component of a vast motorway system, the 240km of M25, fed by 10 major roads, all paid for and operated by the public sector. The bridge, and its sister tunnel, are practically in a monopoly position for that whole system. Owning it and keeping the tolls is equivalent to building the pay areas at a great national stadium and being allowed to pocket the gate money. It is like Las Vegas without the risks, and it is not surprising that it makes money.

Then how could Skye manage with its market of a mere 10 000 souls at the better end? The state is able to give the necessary support in many ways and at the various levels of Eurofunds, Scottish Office funds, regional council funds, and district council funds. The land, the legislation, and planning permissions can be provided and the approach roads given. The ferry's withdrawn subsidy could no doubt be considered. The tolls can be adjusted and policing can be on the rates. There is no reproach intended in this analysis, but simply an effort to show that if you want a project to succeed you have to take the necessary means[2]. That this assertion is obvious does not mean that it is often adhered to.

The world's greatest private entrepreneur of public facilities at present is Mr Gordon Wu. His projects are on a heroic scale. He delights the premiers and presidents of China, Philippines, Indonesia, Pakistan, Thailand and India with his power stations, highways, and mass transits as much as he fascinates the commentators of the financial industries. His techniques, successes and failures bear out most of the assertions in this note. He often employs Arups as his civil engineer and general consultant. He does not ask us to be a shareholder in the schemes or to fund them to any extent in other ways. We must hope that his health remains for many more years as good as it is today.

The reader who finds this torrent of 'publics' and 'privates' intoxicating need not feel guilty. We use these words more Lewis Carroll-style than *1984*-style to mean what we want them to mean. The private sector is full of public limited companies. In the public sector there are many Private Secretaries - as if a secretary could be anything other than private. Britain is too private especially in its public sector, as compared to the USA for example. There is even a *Public* Finance Initiative - which dare not say its name - whose aim is to increase the public sector's involvement in provision of private services. It includes the means for the huge inward investment which has brought Samsung, Chung Hwa, Nippon AG, Siemens, Delta, and many others to Britain.

2. The revenue at Kyle turns out to be not totally controlled. The sheep have been paying to cross if they go by car or float, but free when by foot. Though they get four feet across free, it is usually a one-way ticket.

2. M25 (Illustration: Peter Speleers)

Arups' contribution

We in Arups have a wide range of opportunities from the current shift out of wholly public to private/public projects. It offers a climate where ideas will get generous consideration and good ideas may prosper. We can use our quickness and open approach to innovate and create winning proposals: we should have ideas, test them, and then promote them. However, we must always bear in mind that reliability for the long haul is essential, even though flair is the key to winning in the first place. In addition to the reliability preference, matters like life cycle understanding and costing may now take their proper place. We must learn to discriminate very early on in situations and pour our effort into projects which *will* happen and into promoters who *will* be chosen. This is possible for us but has not previously been a characteristic necessary for our survival. It will make us less tolerant, and unwilling to play wait-and-see. We have to keep away from dopes, from the unbankable, and from confidence men. Whilst we will have systems for reporting and deciding on situations, the essential skill will be in addition to the systems. One can call it luck, nose, or instinct, according to taste.

3. Countries in South East Asia with Hopewell/CEPA PFI projects.

We will get asked to put up some of the capital for a scheme. Fundamentally we should not do so. Put in more politic language we should do so only in exceptional situations. Our attractions to a promoter have to be our high professional skills, our experienced people, our contacts, our comfort with regulations, our large global network, our large teams, our multitude of skills, our mix of nationalities, and our attitude to the conversion of problems.

We do not ask the funder to contribute some of the key engineering skills resource. If our tiny capacity to provide capital makes the difference between success and failure for a new project, we have to question its chances of overall success. We get asked to provide capital when we are vulnerable: before we get appointed. It is leverage on us and should be seen as such. It is remote from the trust, relationships, and enjoyment which we state as our aims. Sometimes a scheme may be a very delicate young thing in its early stages, and attractive to us for some reason. We should be able to give some of our resources to highly likely cases where we know and trust the people, accepting that we may lose that investment but arranging that the risk is highly geared in our favour should success be achieved. Nonetheless the key contribution from us, and hence attraction of us, has to be the deployment of exemplary skills which are relevant to the complete project scope.

Conclusion

In summary, private finance for public projects is a 'how' issue and not a 'what' issue. It ought to have a better name, possibly Project Franchise Programme. Given that these projects are likely to yield good long-term returns for large initial expenditures, the time profile of their money is the counter match to that of pension funds which want to place current capital to meet future spending streams. Perhaps PFI could stand for Pension Funds Investments. Let's see how long before governments tell us to do so.

It may be impossible to achieve, but the whole PFI process could be so much more successful if it were depoliticised. All the main British parties support it, though that does not prevent them from fighting over it. There are lots of issues which should be politicised, but we should all see PFI as a process and not as a principle. The public sector retains the roles, beyond the private franchising, of defining what is required and of regulating the operation of the chosen franchises. Then as the private sector gets more competent at running these para-utilities, as technologies change, as demand changes, as alternatives emerge, our governments should feel able to revisit each item periodically and adjust the framework and the franchises to match the new optimum interface for the public and private parts of the nation.

This personal view has been developed from a lecture given to the Labour Finance and Industry Group conference at the Institution of Civil Engineers, February 1994.

4. Below: Skye Bridge (Guthrie Photography)

Edinburgh International Conference Centre

Alastair Bisset

Context

In 1988 a masterplan competition was launched for a new Edinburgh financial district on a large site stretching 350m along the Western Approach Road from Lothian Road to the Morrison Street bridge. The Edinburgh International Conference Centre (EICC) was just one element of this. The competition was won by Terry Farrell and Company and a masterplan for the whole site was worked up; it located EICC where the Western Approach Road is crossed by the Morrison Street bridge, a position which would make it an anchor point for the new financial district. The plan was accepted by the joint clients, Edinburgh District Council and Lothian and Edinburgh Enterprise, and was granted planning permission in November 1991. Terry Farrell and Company were subsequently appointed as architect for the EICC building itself. Ove Arup & Partners Scotland had not been involved with the original masterplan, but were civil engineering consultants for re-aligning the Western Approach Road before work began on EICC, and were now appointed for the structure and mechanical and electrical services of the building itself.

Site history

The site had been occupied by railway lines funnelling trains into the Princes Street passenger and Lothian Road goods Stations. These were closed in the 1960s and the whole triangle of land between Lothian Road and Morrison Street Bridge became derelict. The route of the railway line was then re-used to form the Western Approach Road, giving Edinburgh a new entry point for light vehicles coming from the west. Nevertheless the greatest part of the area was still derelict and was identified as requiring resuscitation in the form of development. This also brought the opportunity for some commercial gain as well as realising the city's aspiration for a conference centre, deemed necessary to bring visitors to the city at unseasonable times of year. Unfortunately the site was traversed by the railway tunnels carrying the main Edinburgh/Glasgow line between Waverley and Haymarket Stations at comparatively shallow depth and thus detracting from the land's development value. This problem was solved by moving the Western Approach Road to a new position over the tunnels (as noted above), thus creating a valid development site.

Site works

The Conference Centre site, at the west end of the development area, had previously been occupied by the lines to the goods station and one side of the railway cutting (Fig.2).

The ground sloped up 7m from the Western Approach Road to Morrison Street and the site was traversed by a geological fault in which the mudstone, siltstone, and sandstone was completely shattered. On one side of the fault the rock was intact, on the other was an outcrop of very hard conglomerate.

To the north-west was the dual carriageway of the Western Approach Road, to the south Morrison Street, and on the south-west the three disused railway tunnels which originally carried the railway lines under Morrison Street. The building is built partially over these tunnels which, indeed, are now used for additional storage for EICC and form an intake to carry cool fresh air into the fully-glazed, south-facing entrance foyer.

1. Edinburgh International Conference Centre in its city context.

2. The site before development, viewed from the Sheraton Hotel on the Lothian Road side, facing south-west. Morrison Street runs from east to west above the three disused rail tunnels, and the Western Approach Road is on the right. The western end of the disused Lothian Road Goods Station was located where the car park is in the foreground. Princes Street Terminus was on the right, out of shot; the Glasgow/Edinburgh main line tunnels traverse that part of the site, running approximately east-west.

3. The site in May 1993, facing south-east, showing the temporary retaining wall to Morrison Street.

4. View from Morrison Street: the main public entrance is on the left.

5. Above: The main foyer.

6. Staircase to the main auditorium.

All these constraints meant a tight site and substantial site formation works. A rock-anchored temporary retaining wall with king posts drilled into the conglomerate was constructed to support Morrison Street so that the site could be reduced to Approach Road level (Fig.3). This involved the removal of much rock including some of the hard conglomerate, which slowed the contractor's planned progress for a while.

The site formation level was some 2.5m below the floor of the tunnels. This meant that the tunnel walls had to be underpinned prior to the excavation. In addition the final buttress of the arches had to be removed to clear the required site area. The tunnel roof was propped to prevent a spreading collapse.

The structure

The concrete pad foundations were formed directly in the rock with the lowest reinforced concrete floor slab just above them at the 63.5m level above Ordnance Datum (OD). A permanent reinforced concrete retaining wall was then formed integral with the ground slab, providing a permanent support to Morrison Street and replacing the temporary wall. The permanent wall was designed as a cantilever, with considerable movement at its head. A movement joint at the head of the wall prevents the transmission of force from the wall to the floor plate. The shear walls are thus relieved from this additional load.

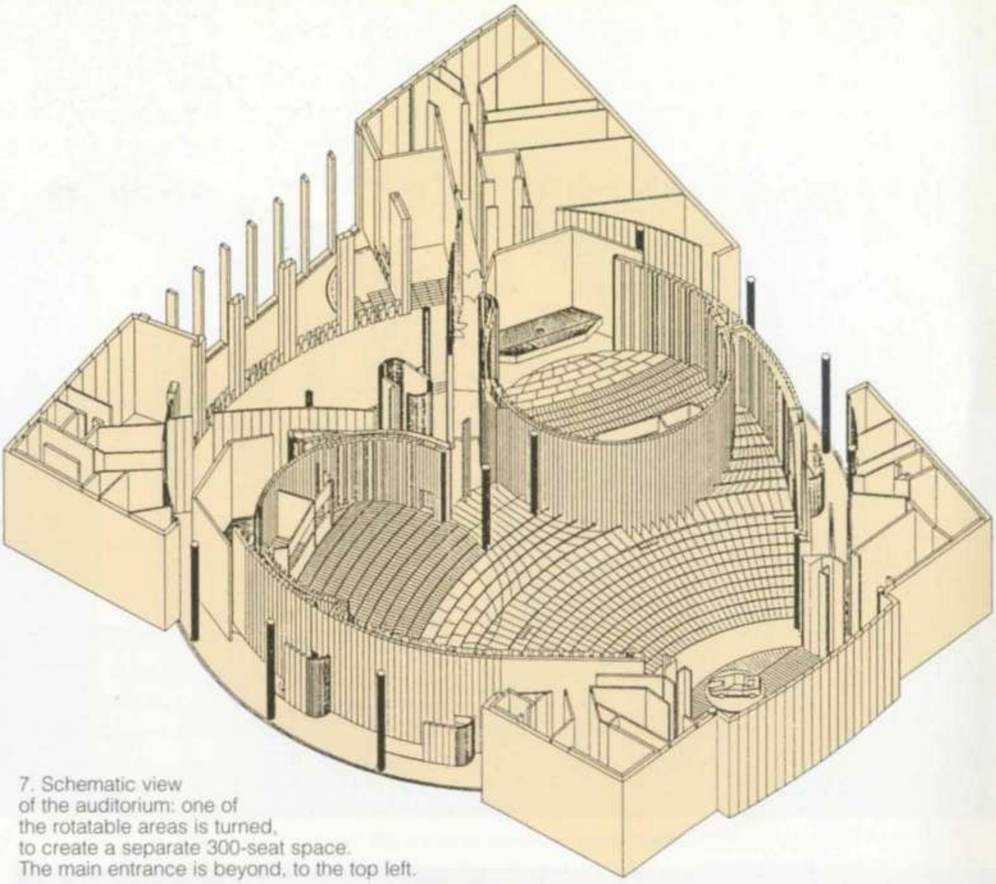
The chosen interior layout of EICC required an exhibition area, plant space, and service yard at the lowest, 63.5m OD level, with a direct entry for service vehicles from the Western Approach Road. The main public entrance to the building is from Morrison Street (Fig.4) at 70m OD level; this houses the main foyer (Fig.5), the 'breakout' rooms where conference delegates subdivide into smaller discussion groups, and the stairs and escalators (Fig.6) which carry them either up to the 44m diameter main auditorium or down to the exhibition hall. The EICC layout reflects the use of the building.

Conferences generally start with a plenary session in the main auditorium at which all delegates are welcomed to the event and hear the keynote speech. They may then subdivide into the smaller groupings to discuss more specialist subjects.

The main auditorium is situated at 78m OD level with the boiler room above its foyer at 87m OD level, and the heat rejection equipment in a special housing on the roof at 92.5m OD level. Packing this varied accommodation and its servicing into the chosen building size and shape posed a difficult problem, which was exacerbated by the client's requirement to have the auditorium subdivisible by the use of two rotatable areas of seating, each accommodating 300, to create separate, minor auditoria (Figs.7-9). These are located at the rear of the main auditorium, which seats 600, and turn through 180° to isolate themselves from it. Each rotating area is supported on a circular rail (Fig.10) which requires careful control of deflection under the varying loads generated by the rotation.

A further consideration was the deceleration force generated by the 20mm emergency stop distance of the rotating drums, which with their cladding and fittings added to the structure weigh 150 tonnes each. This force is taken out through the floor plate to four concrete cores at the drum perimeter. The problem is further complicated by the need for acoustic separation of each area from its neighbour. Each of the areas, including the stage, the simultaneous interpretation (SI) booths, and the projection rooms, has to be serviced in both configurations.

The superstructure below the 70m level is an irregular quadrilateral plan shape and is constructed in in situ reinforced concrete.



7. Schematic view of the auditorium: one of the rotatable areas is turned, to create a separate 300-seat space. The main entrance is beyond, to the top left.

8. Left: The auditorium in 600-seat mode and
9. Below left: in 1200-seat mode.

The frame package tender documents had called for alternative bids for steel frame and in situ concrete solutions up to the 70m level, and the winning subcontractor elected for the latter with the offer that this would save three weeks from the programme and £200 000 from the price.

Above the 70m level the structure consists of a circular drum framed in steelwork (Fig.11). The radial beams are supported at the centre on four circular steel columns (Fig.12) and at the perimeter of the drum on 12 similar, regularly-arranged columns.

At auditorium floor level the beams are of the proprietary Cellform type, up to 1.7m deep with large circular holes cut from their webs to allow the passage of minor services. At roof level the loads were so large that the use of welded plate girders was required, again up to 1.7m deep in the middle but tapering to 900mm at the edge. Despite its complication, however, the frame was built in nine months.

The exterior surface of the drum is clad in precast units (Fig.13), which, rather unusually, are supported on steels which are hung from the roof and auditorium beams respectively. That is, the whole of the drum cladding is hung from the steelwork above, which led to some interesting calculations of the expected deflections, especially where the drum cladding abutted the stair core where the stone cladding was directly supported on the concrete structure of the stair tower. Also supported from the roof are lighting bridges, escape walkways, SI booths and even one side of the boiler house.

10. The auditorium under construction: the rail supporting one of the rotatable units is visible in the foreground.

11. Progress on site by November 1993, showing the steel structure of the auditorium drum.

12. The four circular steel columns supporting the drum.

13. Above: Precast units on exterior of the drum.

14. Below: The main entrance.

The floor and roof beams act compositely with the concrete floor slab. The four irregularly shaped concrete stair towers are each attached at the perimeter of the drum. These contain stairs, toilets, and vertical ducts for services and support external services plant on their roofs. Special provisions had to be made for provision of temporary stability to the drum during construction.

A specialist-designed fabric entrance canopy is supported on 'wave'-shaped steel beams cantilevered out from steel columns which stand clear of the face of the building. The ends of the cantilevers are held down against wind uplift by rod ties at their external ends. The lower ends of these tie rods are cased in concrete to protect against vehicle impact from the adjacent vehicle set-down layby (Fig.14).

15. The auditorium with one rotatable section facing forward; the main lighting is by recessed, dimmable downlighters.

The services

The Conference Centre has two separate electrical supplies, each from a different Scottish Power substation. There is also an emergency generator which powers essential items, such as food freezers, computers, and security and firefighting systems. As would be expected in a building of this quality, much attention has been paid to the achievement of the desired lighting effect. Low wattage downlighters are used in the public areas to aid energy conservation. In the auditoria and breakout rooms the general lighting is provided by dimmable, double-focus downlighters recessed in the ceiling (Fig.15). The lighting needs in the exhibition hall are quite different so that an indirect dimmable light source is employed for the house lighting. All public areas have 'mood setting' lighting controls, so that the ambience of the space can be altered to suit the nature of the event in progress. External lighting is concentrated at the top of the drum and illuminates the underside of the crowning roof disk.

This creates a floating effect and enhances the Centre's visibility on Edinburgh's after-dark skyline. The striking entrance canopy is also suitably illuminated to draw people to the doors.

Power supplies include three-phase temporary supplies to exhibition hall stalls served from openable floor trenches, floor box outlets in the foyers for flexible use of that space, and special voltage-stabilised electrical supplies in the auditoria, lighting control, dimmer rack, and projection rooms.

There is a data distribution system installed throughout the building with the capability of handling press conferences, television outside broadcast, satellite television, and so on. Vertical transportation in the building is provided by seven lifts and five escalators.

The heart of any conference centre is the main auditorium, which is kept under close temperature and humidity control at all times. The heating or cooling requirements for the space vary enormously as the auditorium fills with delegates and the high-powered stage lights are switched on for the plenary session. Large air ducts supply tempered air through ceiling-mounted diffusers and extract air from lighting gallery level as well as from under the seats. This air is rejected to outside atmosphere, or it is heated or cooled for recirculation as required by internal and external conditions. Duct sizes were kept large so that the noise of the air passing through them is minimised.

The gas-fired boilers are located high in the building immediately over the entrance foyer to the auditorium. The air-handling units and the heat rejection equipment are placed above the boiler plant at the top level and within the distinctive roof disc.

The services for this particular auditorium are of course complicated by the requirements for subdividing the space into the three separate smaller auditoria, with their completely separate services systems. These must function equally well both together and separately, and are controlled in the different auditoria configurations by the Building Automation System. The auditorium ancillary areas such as projection rooms, control rooms and simultaneous interpretation booths, all require separate dedicated air systems. Many of the auditoria systems are replicated on a smaller scale in the breakout rooms which are situated on the main entrance floor.

These rooms are also divisible, in this case from 600 seats to three 200-seat spaces. A similar but smaller-scale system operates in the subdivisible committee rooms. The entrance foyer itself is flexibly serviced to deal with delegate registration, assembly, buffet and bar service and minor exhibition use.

The exhibition area is situated on the lowest floor at Western Approach Road level and adjacent to the heavy vehicle loading bay. The temporary exhibition stands can be provided with the water, electricity, telecommunications, or drainage services they require by two floor ducts, one wet and one dry. The ceiling-mounted services include air ducts, lighting, and strong points for suspension of heavy exhibits. The services have been designed to a much higher standard than normal for this kind of space in order to cater for the grand banqueting functions which can be held in the exhibition area.

Contract

The contract was a management type with a guaranteed maximum price. The design team appointment was novated from the client to the management contractor soon after the latter's appointment. The total cost of the building was some £35M.

Conclusion

Sunday, 17 September 1995 saw the official opening by Tom Farmer, chairman of Kwik-Fit and one of Scotland's most dynamic and enterprising businessmen. In his introductory remarks he said '... perfection... that is what has been achieved today; it is perfection.' Even though that was prefaced by a guess as to what the City Fathers of 25 years ago might have expected, it was still very high praise indeed.

Credits

Client:
EICC Ltd

Architect:
Terry Farrell and Company

Structural, mechanical, and electrical engineers:
Ove Arup and Partners Scotland
Douglas Wylie, Robin Woodger, Willie Stevenson, Fred Robinson, Alan Richmond, Gerry O'Brien, Ian McGarrity, Ray McIvor, Jim Hampson, Willie Crowe, Alan Coventry, Annalisa Coutts, Tim Cromack, Dorothy Brankin

Acousticians:
Sandy Brown Associates

Quantity surveyors:
Gleeds

Construction management:
GA Construction

Illustrations
1, 4-6, 8, 9, 14, 15 : Keith Hunter Photography
2, 3, 11: GA Construction
7: Sandy Brown Associates
10, 12: Ove Arup & Partners Scotland
13: EICC

Pride Park, Derby

Peter Braithwaite
Sue Wade
George Webb

Introduction

In 1992, Derby City was among the local authorities to win the second round of the DoE City Challenge Programme, and Derby Pride Ltd was set up to administer the funding necessary to deliver the City's goals. Pride Park, the flagship proposal, was to be located on 80ha of largely derelict land near the city centre, previously used for domestic/industrial landfill, coke, gas, and heavy engineering works, and gravel extraction. It was heavily contaminated with pollutants including oils, tars, phenols, heavy metals, ammonia, boron, and even some low-level radioactive material below the landfill.

Several parts of Arups became involved when in August 1993 the Birmingham office were appointed as reclamation engineers to develop and implement the strategy to convert the site to a mixed commercial, leisure, and residential development. By this time, there had already been several site investigations, identifying major issues to be addressed prior to any building. Some 800 soil samples had been taken for chemical testing, each for a total of 22 different determinands.

The site

Pride Park is jointly owned by British Gas, BR Property Board, and ABB Transportation. The site is generally level; to the north and east lies the River Derwent, and to the south and west, the main rail-line between Derby and London. All buildings have been demolished, except two large gasholders. The former Derby-London Canal (now completely filled in) runs through the site, as does a major trunk sewer. In general, the soils follow the sequence: fill (up to 7m thick) overlying alluvium, terrace gravels, and Mercia mudstone.

Contamination

The first challenge for Arup Environmental was to assess the mass of chemical data and present it comprehensibly. All soils test results were divided into groups of metals, inorganic compounds, organic compounds, and other hazards, resulting in five sets: toxic metals, phytotoxic metals, cyanides, organics, and miscellaneous.

As there are no nationally recognised comprehensive guidelines for contaminated soils and water, a site-specific classification system was developed. Within each set, every determinand was allocated a 'class' on a scale of 1 ('uncontaminated') to 4 ('very contaminated'). The maximum values in each were, wherever possible, based on available guidelines, eg ICRCL (Interdepartmental Committee for the Redevelopment of Contaminated Land), Kelly, and Canadian Council of Ministers of the Environment (CCME).

Water

Groundwater samples were also classified 1-4, though this scale,derived from EC Directives, differs from the soil classification system.

Gas

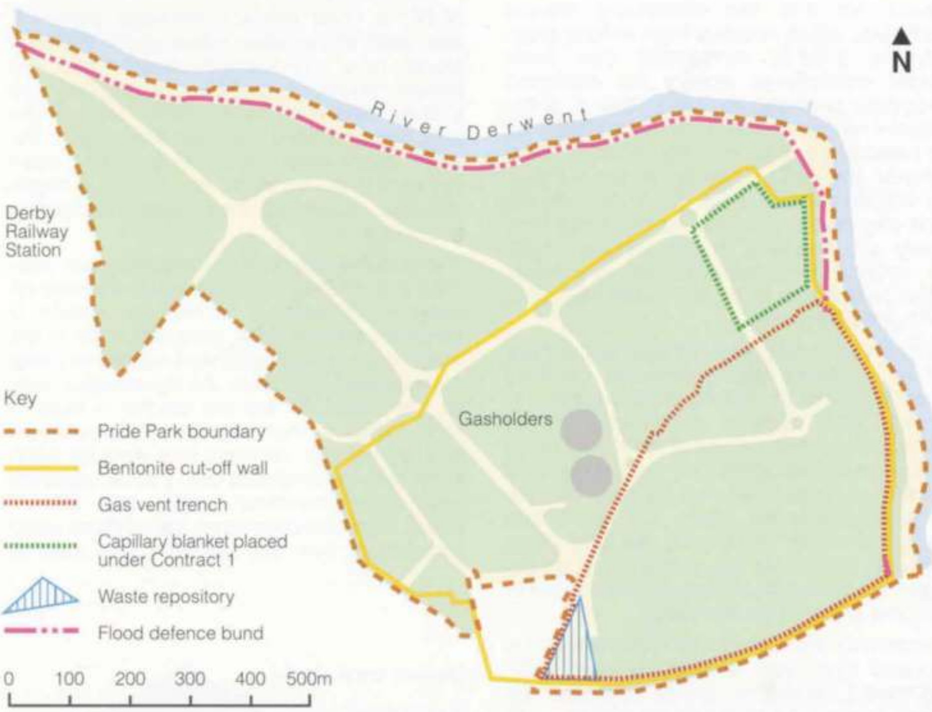
Borehole measurements had found a continued gas presence in the landfill part of the site. These are expected to reduce in the long term but developments close to the landfill are likely to require gas protection measures built into their substructure.

Constraints

With the site-specific soil and water classifications developed, all the determinands were put in a database, and each sample given an overall classification based on the highest for any parameter measured. As samples were recovered from discrete depths, it was then possible to create a 3D contamination model which was used as a 'constraint model' for 'hot spots' of particular contaminants and areas of generally contaminated soils and water. For example, it can be used to identify the constraints imposed by class 4 'very contaminated' soils or for particular determinands.

This flexibility is important as, for example, a class 4 phytotoxic metal may not impose the same constraint as a class 4 phenol level for an area which is to have a commercial or industrial after-use. The model can also plot contaminants at various depths below surface, again of prime importance when determining remediation options.

1. Site before investigation.



2. Site plan.

3. Aerial photograph looking east.

These analyses indicated that the site generally could be split into east and west halves. The former comprised old landfill and gas works with mostly contaminated soils and even more highly contaminated groundwater, whilst the latter - gravel pits and engineering works - had localised and impersistent areas of contamination both in type and level. The groundwater under this area was generally uncontaminated.

Reclamation strategy

Two principal objectives were to minimise off-site disposal of contaminated soils, and to ensure that contaminants do not migrate into the Derwent, on the north and east site boundaries.

Developing the strategy was simplified by the constraints model. To the east, the high contamination levels extend to 10m below the surface, which made treatment impractical and uncommercial. The area has thus been safety-contained within a 600mm minimum-width bentonite cement vertical cut-off wall, sealed 1m into the underlying Mercia mudstone, within which a high density polyethylene (HDPE) membrane has been placed centrally to ensure the designed 10^{-8}m/sec permeability. Construction of the 3000m+ length of wall was complicated by the need to enclose existing services whilst ensuring the wall's integrity. At the surface, the wall is capped by a 5m wide, 500mm thick clay cap to prevent the bentonite from drying and cracking. A gas venting trench will encircle the closed landfill to prevent pressure build-up or landfill gases migrating to neighbouring sites.

Parts of the landfill and old gas works sites will be surfaced with permeable capillary break blankets as individual developments require. Their 650mm thickness and the grading of the stone material are designed to ensure that in periods of drought the capillary rise of any contaminant will be less than the blankets' thickness. Rain can percolate through and into the landfill, but end users will be protected. As rain passes through the waste, soluble contaminants will be carried to the base of the fill as leachate.

To minimise the amount of materials to be removed from site, a purpose-built, fully-engineered landraise, jointly designed by Arups' Leeds and Birmingham offices, is to be constructed within the bentonite cut-off wall to take 36 000m^3 of class 4 soils from the rest of the site. Its design includes a composite clay/HDPE lining with leachate drainage and landfill gas wells, and it will have an impermeable cap, over which a soil covering will permit vegetation and landscaping.

The western part of the site will have less intensive treatment, with local removal of contaminated soils. Further chemical testing will yield results to be classified in accordance with the site specific classification and added to the database. The constraint model can therefore be continually refined as more data becomes available.

Environmental Statement (ES)

The waste repository, now designed, is the subject of an ES called for by the Waste Regulation Authority, Derbyshire County Council. It has been submitted to them together with a waste licence application. The ES, prepared by Arups, describes in detail the proposed construction of the waste repository. It concludes that it should not have any major adverse impact on the environment; indeed, its location inside the vertical cut-off wall will afford double protection.

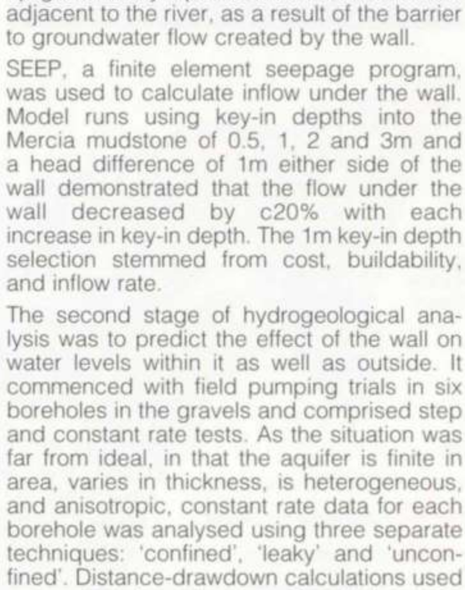
Groundwater modelling

A two-stage hydrogeological analysis modelled groundwater conditions before and after construction of the cut-off wall. The first stage program, AQUA, set the model boundary conditions as either 'no flow' or 'fixed head', and predicted the natural groundwater conditions within the site. The parameters were calculated using the known groundwater abstraction at the adjacent sand and gravel quarry within the modelled area and comparing the predicted groundwater drawdown with that measured in the field.

The containment wall was introduced into the model by creating a 'no flow' boundary. Groundwater levels outside the wall rose up-gradient by up to 0.7m and decreased adjacent to the river, as a result of the barrier to groundwater flow created by the wall.

SEEP, a finite element seepage program, was used to calculate inflow under the wall. Model runs using key-in depths into the Mercia mudstone of 0.5, 1, 2 and 3m and a head difference of 1m either side of the wall demonstrated that the flow under the wall decreased by c20% with each increase in key-in depth. The 1m key-in depth selection stemmed from cost, buildability, and inflow rate.

The second stage of hydrogeological analysis was to predict the effect of the wall on water levels within it as well as outside. It commenced with field pumping trials in six boreholes in the gravels and comprised step and constant rate tests. As the situation was far from ideal, in that the aquifer is finite in area, varies in thickness, is heterogeneous, and anisotropic, constant rate data for each borehole was analysed using three separate techniques: 'confined', 'leaky' and 'unconfined'. Distance-drawdown calculations used parameters from the pumping trial data to establish drawdown at the wall as a result of pumping from abstraction boreholes.



4. Isometric of cut-off wall.

Data from the pumping trials was incorporated into the stage 2 AQUA modelling with the range of permeabilities deduced from the pumping trial data assigned to different areas in the model.

Only minor changes in the output of the stage 1 models were evident. Two further AQUA models were defined, one simulating the wall as a thin low permeability area with nodes on both sides and one only using the area within the wall. Both indicated that boreholes set near the wall reduced water levels there by the required amount, whilst levels in the centre of the site were largely unaffected.

The second stage also comprised inflow and upflow calculations into the contained area as a result of the difference in piezometric head between the underlying Sherwood sandstone (approximately 44m OD) and the gravels. Further refining of the model and analysis with SEEP and AQUA showed that the total flow of groundwater to be abstracted is around 30l/s.

The pump and treat system

To reduce the groundwater levels inside the cut-off wall to below those on the outside, a system of abstraction and treatment of the groundwater to prevent risk of pollution will be installed. The appointed contractor will prepare the detailed design of this system under a design and build contract. Arups' scheme modelling has indicated that c45 boreholes will be required, offset 5m from the wall - a distance fixed by Derby Pride Ltd due to their easement requirements. The anticipated spacing is about 50m in the area near the river where the wall height is lower than 42.5m OD, and about 65-70m over the rest of the site.

Although the National Rivers Authority (NRA) initially required a 1m average head difference over the entire length of the wall, it has been agreed that 0.25m will be maintained by the river and railway with water levels elsewhere kept 'at or below' those outside the wall. This may significantly reduce the amount of water to be abstracted.

The abstracted water will be pumped via a ring-main system to the treatment plant in the corner of the site and directed through a series of water treatment systems before discharge to the river. The level of clean-up will comply with the NRA's Discharge Consent, and will not be detrimental to river quality.

Pairs of monitoring boreholes (either side of the wall) spaced regularly to monitor water levels inside and outside, will trigger the borehole abstraction system. Water samples from these boreholes will be tested for pH, suspended solids, chemical oxygen demand (COD), biological oxygen demand (BOD), ammonia, boron, heavy metals, oils and tars, and phenols to assess the system's success.

Once commissioned, it will operate for at least 15 years. This should clean up much of the contaminated groundwater, leading to reduced treatment towards the end of the operating period.

Environmental monitoring

During the wall's construction, noise and dust were monitored, the latter at four places in the surrounding residential areas; this generally indicated that both remained within limits during the works. Gas monitoring, also during construction, showed that elevations of gases were generally isolated and located within the landfill area. This is still ongoing. River monitoring at four points along the length of the whole site, over a 19-month period, included inorganic and organic analysis. No discernible trends were noted, either before or after wall construction.

Groundwater monitoring, comprising water level and chemical analysis, began in 1993 over the entire site in a limited number of boreholes. More regular monitoring commenced in May 1994 in boreholes inside and outside the wall, in particular where it was near the river. All this revealed seasonal trends and that water levels within the wall are higher than outside, in particular close to the river. The level rose rapidly, up to 4m, as the wall was being built and in the months immediately following completion, attaining a general water level of 43.5-44m OD over the site. Levels inside the wall were thus higher than the top of the wall in the areas by the river and railway which are approximately 43m OD. The rise may have been partially caused by the construction method; as required by the NRA, sections of the wall by the river were the first parts to be built. This created an immediate barrier to groundwater flow and allowed levels to 'build up' behind the wall. The rise was also caused by the large winter rainfall and upflow from the underlying Sherwood sandstone.

From March to December 1995 levels in the site decreased, though slower than the previous rise and not reducing to pre-wall levels.

5. Lowering HDPE membrane into wall.

Recent monitoring indicates that levels are again rising and, if this continues, temporary abstraction wells will be installed for immediate control, pending installation of the permanent abstraction system.

Groundwater contamination, including organic and inorganic parameters, has been monitored in detail in boreholes inside and outside the wall since construction began in May 1994. A more comprehensive suite of tests including Red List substances, furans and dioxins were undertaken on fewer boreholes on a limited number of occasions. The main elevated parameters are boron, COD, ammoniacal nitrogen, sulphate, sulphide and electrical conductivity, although there are also significant areas of elevated polyaromatic hydrocarbons. Chemical monitoring continues bi-monthly in a limited number of boreholes.

National Rivers Authority

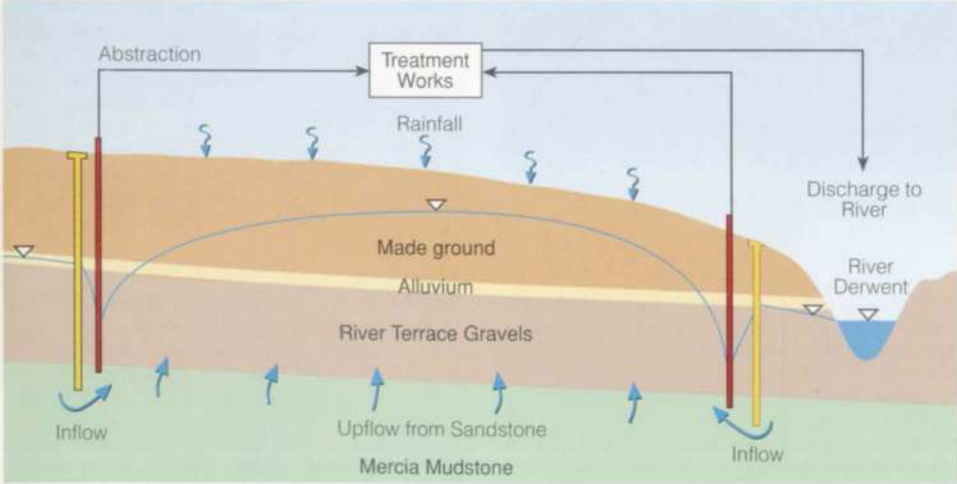
Close liaison with the NRA through every stage of the reclamation process has been a key feature of the project, and the good relationship has greatly assisted in the project's smooth running. The NRA have had particular involvement in:

- Input into the feasibility of the wall stopping contamination migrating into the river
- Input into order of construction of the wall - length adjacent to river built first
- Environmental monitoring - groundwater and river water
- Provision of background design data - river flows and levels, flood level data, and licensed abstractions
- Pumping tests - Consent to Test Pump required from NRA under the Water Resources Act - Section 32(3)
- Pump and treat system:

  (a) Abstraction Licence required for extraction of groundwater within wall

  (b) Discharge Consent required for discharge of treated groundwater into River Derwent. Concentrations of contaminants within discharge to be specified in a consent.

Once the abstraction and treatment plant is operational, the NRA will become further involved in monitoring and liaison to ensure that the Discharge Consent limits remain in compliance.



6. Pump and treat system: idealised cross-section through site.

Recent construction work

The first phase of reclamation started in May 1994. Contract 1 included the bentonite/cement cut-off wall, partial reclamation of two development plots, and well-pumping trials.

The value of the contract at tender was £3M. Further land reclamation was added to the contract, which allowed the subsequent construction of roadworks above the reclamation platforms. The roadworks, designed and implemented by Derbyshire County Council, include re-routing the main A6 Derby-London road through the site. Construction of the 3km long cut-off wall was carried out by Bachy, Morrison's sub-contractor, who in the tender negotiations had queried the compressive strength and strain requirements of the specification. It was eventually agreed that the requirement for strength could be relaxed providing that for strain was met; flexibility of the wall being the over-riding factor.

The work on site proceeded without any major problems though the service crossings through the wall proved more difficult than first envisaged. Firstly, there were more live services than expected and secondly, the amount of water entering excavations for the two Northern Interceptor sewer crossings delayed this part of the work by some weeks.

Future proposals

The first phase was completed in June 1995, and the contract for groundwater abstraction and treatment system went to tender at the end of January 1996. A notice had to be placed in the Official Journal of the EC due to anticipated operating costs being above the stated threshold for a Public Works Services Contract. Other work planned for the next year includes construction of the waste repository, flood bund, and vent trench. As well as this, it is likely that further development plots will require reclamation as and when prospective purchasers appear, with each having reclamation works tailored to suit their own project requirements.

Credits

Client:
Derby Pride Ltd

Consultants:
Ove Arup & Partners Tracey Bailey, Robert Blair, Peter Braithwaite, Ian Burwood, Adrian Collings, Stuart Cowan, Chris Evans, Jide Fakoya, Steve Gazeley, Lee Gill, Terrie Hall, Martin Jennings, Tom Kennedy, Robin Lee, Nigel Livingstone, Peter Neville, Crispin Oakman, Steve Ryall, Keith Seago, Will Sims, Keith Small, Alan Turner, Sue Wade, George Webb, Kevin Wood, Stewart Yalden (Birmingham)

Chris Barrett, Chris Carter, Brian Coyle, Linda Dewar, Bruno Guillaume, Ginny Hyde, David Oram, Richard Owen, Dermot Scanlon, Lorna Walker, Simon Witney (environmental, London)

Lisa Gledhill, John Henry (geotechnics, London)

Colin Copeman (Coventry)

Peter Chamley, Deborah Lord, John Theos (Leeds)

Hakop Mirzabaigian, Rob Paris (Manchester)

Robin Lee (Nottingham)

Finola Reid (Arup Acoustics)

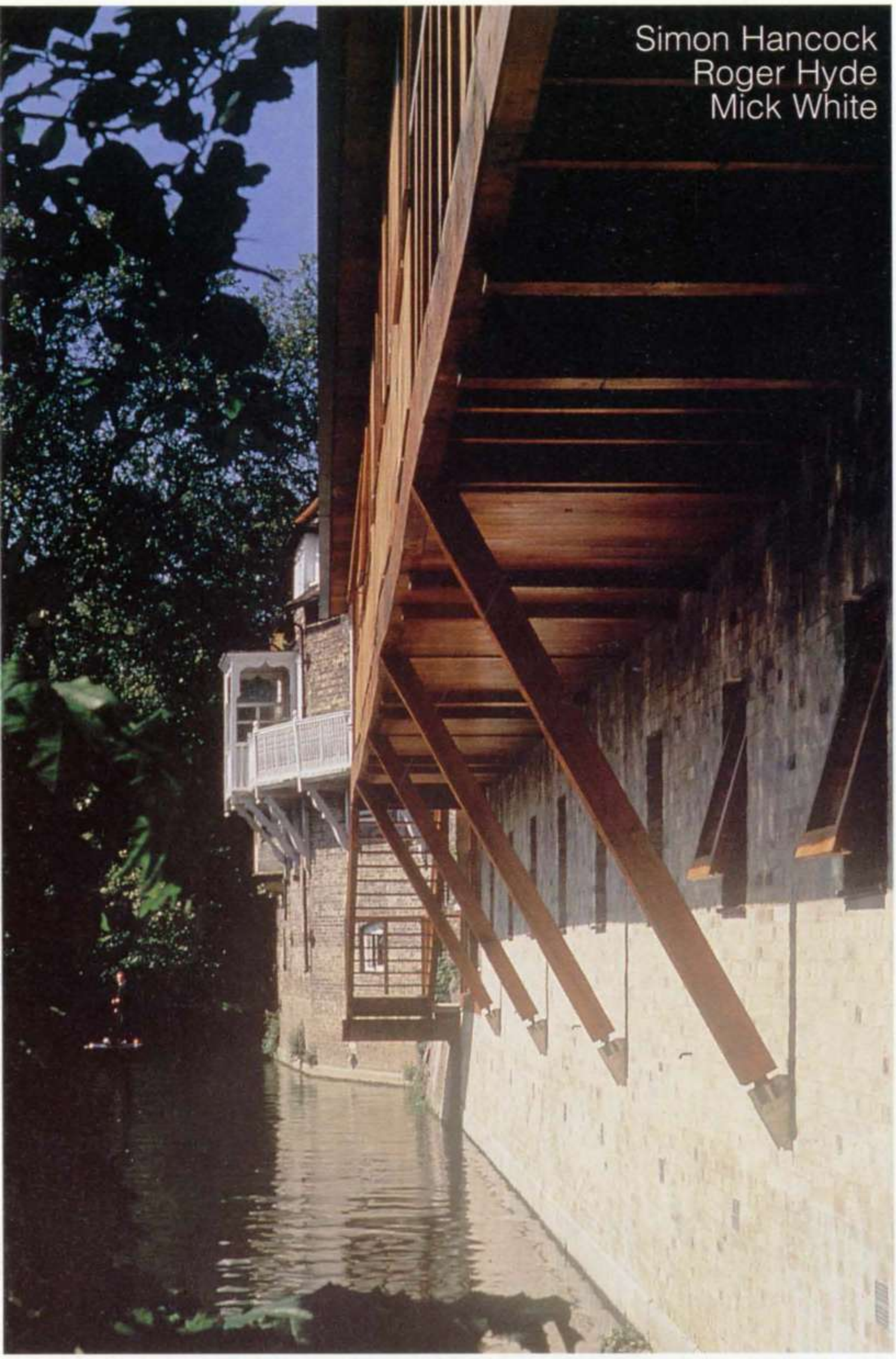
Phase 1 reclamation contractor:
Morrison Construction Ltd

Cut-off wall sub-contractor:
Bachy

Illustrations:
1.&.5: Peter Mackinven. 2: Jennifer Gunn.
3: SAM Design Consultants.
4: Sean McDermott. 6: Claire Noble.

Darwin College Study Centre, Cambridge

Simon Hancock
Roger Hyde
Mick White



1. Darwin College: Oak beams support the cantilevered study area over the River.

Introduction

Darwin College, Cambridge, was founded in 1965 as the first postgraduate college in the University. It lies between Silver Street and the River Cam, with new buildings infilling between existing buildings once lived in by the Darwin family (the most famous being Charles of *Origin of Species* fame). The site is at the eastern end of this progression, 45m long and from 6-8m wide. During the summer, tourist coaches park in Silver Street beside the Study Centre, while across the River (or mill pond as it effectively becomes at this point), where punts may be hired, is Laundress Green, much used for sitting out and picnics. The college had increasingly felt the need for extra study facilities, particularly with the growth of computerised information sources. In 1988 an architectural competition for a new Study Centre was held, and won by Jeremy Dixon. Arups were appointed as building engineers in January 1990, but a planning appeal delayed detail design until 1993-4. The Centre provides some 70 work spaces and 30 computer terminals (all linked to the University network), and includes a seminar room and a Fellows' flat. The building is on two levels; the upper, containing the study areas, cantilevers over the Cam (Fig.1).

The straight line of the waterfront joins the curved wall of Silver Street to generate the warped monopitch roof that is a dominant interior feature. In response to client requirements and the difficult site, the design team developed the following aims:

- a quiet, naturally-ventilated building, in which good natural lighting would provide a range of working environments
- retention of the form and sense of the original boundary walls with, as a consequence, no joints in the brickwork
- a prominent use of oak: shown in the structure primarily, but also in windows, floors, bookcases, and furniture.
  Each part of the whole was to be visibly linked by the nature of the material, expressed in detailing of joints, textures and finishes.
- buildability: the site was 6m wide at its narrowest, and had the river on one side and the tourist coaches' parking on the other. Sluices up and down stream meant that the river could be lowered between November and March, easing construction of the river wall.

These objectives were achieved by combining traditional materials with both modern materials and engineering systems.

Environmental

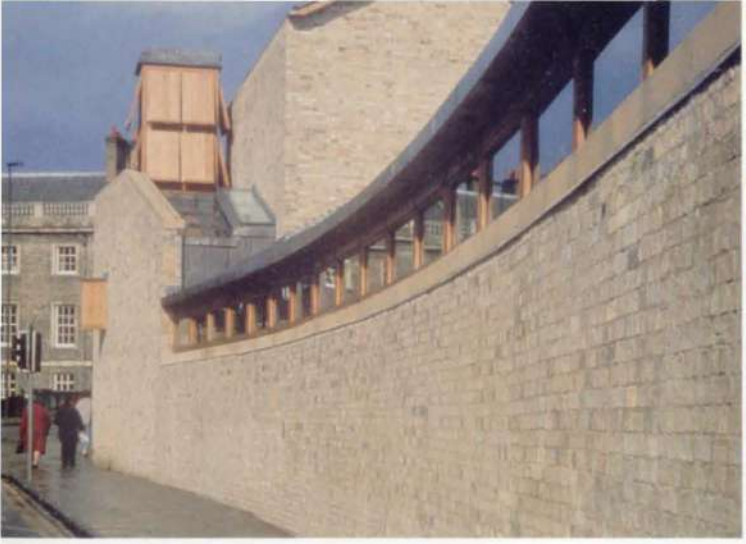
The noise and pollution from Silver Street, and particularly the parked tourist buses (which run their engines to keep the air-conditioning going), meant that simple cross-ventilation was not possible; in fact the wall, window, and roof adjacent to Silver Street were designed specifically for noise exclusion (Fig.2).

Computer studies were made of aspects of the internal environment. Arups' GATHER software was used to investigate daylighting, whilst the VENT program showed that if natural ventilation were to be effective, cool air would have to be induced into the building and drawn along its length progressively, feeding up to high level and out. The solution was to use the riverside windows at clerestory and first floor level, coupled with a lantern at the east end acting as a ventilation stack to create a longitudinal air flow and 'make a circuit'. The high level windows and lantern side flaps open and close automatically with air temperature, wind speed, or rain. First floor windows are manually operated. Stable-type doors opening onto the river (Fig.5) were introduced between working areas to create good general air flow (Fig.6).

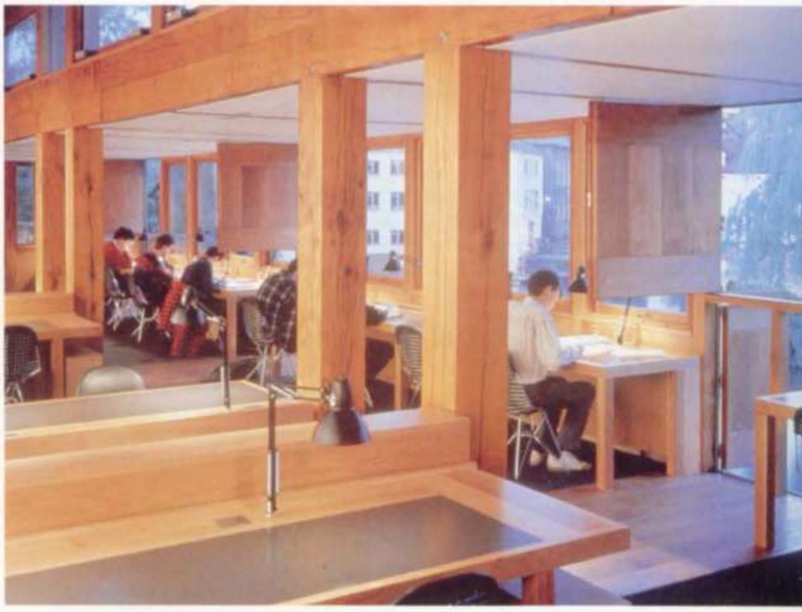
The ground floor computing rooms have small windows to reduce screen reflection (and for security), and were provided with fan coil heating and cooling. This allowed them to be closed off from the rest of the building, reducing noise from keyboards and printers. The computer rooms also have raised floors for cabling and services. Underfloor heating is provided in circulation areas with radiators under windows.

Structure

The building is founded on continuous flight auger bored piles, with a hinged link to the adjoining and structurally frail Old Granary Building. Ground beams, river walls, and precast floor provide a structural deck which supports a load-bearing masonry and timber superstructure.The external brickwork used lime putty/sand mortar, which avoided the need for movement joints because of its natural plasticity and greater ability to absorb movement. All brick walls are solid - one brick thick generally, but one and a half on Silver Street - both for structural stability and acoustic insulation.



2.
The roadside wall, with the 'ventilation stack' lantern at the rear left.



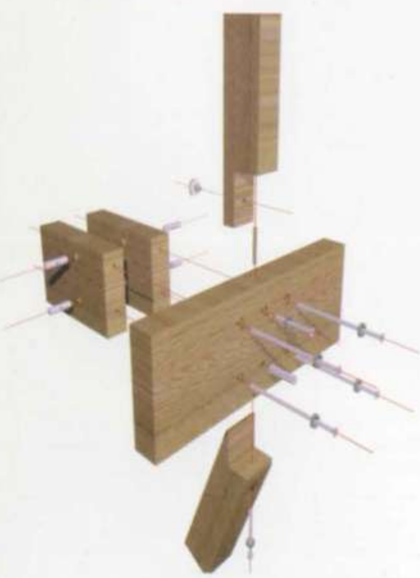
5.
The study area, showing oak timber structure and 'stable' doors giving natural ventilation.

Jointing the timber

The connections between main structural members were arranged so that they could be tightened as drying of the timber took place. Loads are largely transferred by timber-to-timber contact, with bolts acting as positioners and ties to maintain the geometry of the joint. Stainless steel was used throughout because of the corrosive nature of green oak. The bolt details are similar to scaled-up furniture fixings, using a countersunk head recessed into a washer, itself recessed flush with the timber (Fig.3).

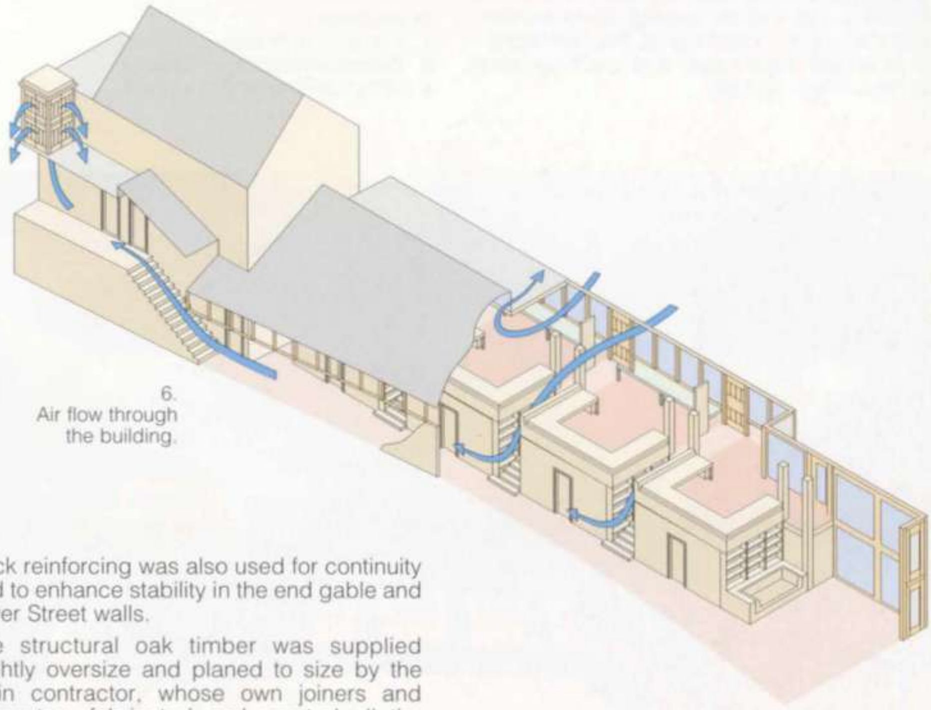
3. Window-frame joint detail.

The design sought to avoid the industrial connotations of conventional bolt heads, or the false suggestion of a dowel if the head has been recessed and plugged.



4. Exploded joint detail.

Rod end anchors were used to connect into longitudinal members, and flush dead end anchors when bolts passed through to the hidden side of a member (Fig.4).



6.
Air flow through the building.

Brick reinforcing was also used for continuity and to enhance stability in the end gable and Silver Street walls.

The structural oak timber was supplied slightly oversize and planed to size by the main contractor, whose own joiners and carpenters fabricated and erected all the structural frame. The members were only available freshly cut: section sizes ranged from 365 x 100mm (river cantilever beams), 250 x 250mm (primary posts), and 250 x 75mm (principal rafters - Fig.7), to 100 x 100mm and 150 x 100mm for general framing members. The range of movements that could occur from 'green' timber was too great to be accommodated, so the oak was pre-purchased and kiln-dried to achieve maximum drying in the three months available before the main contract started.

7.
Pitched roof beams.

The effectiveness of accelerated drying of large sections is not documented: it was recognised that the timber would not be fully dry on installation, and that in service there would be fissuring, across-grain shrinkage, and distortion of line in rough proportion to the member thickness. The potential long-term movements were estimated, and joints and interfaces with windows and furniture designed for these movements.

In fact moisture content at installation was between 26-60% - substantially higher than hoped for - and this has caused some greater drying movements than were planned. It was also a reminder that this particular European hardwood remains unpredictable in large sections, and requires robust detailing and a conservative assessment of drying shrinkage.

The main roof rafters are the members most susceptible to creep deflection and distortion, and were designed to act compositely with the double-layer plywood roof deck, which also formed a structural diaphragm to transfer wind loads to the end walls.

The decision to use oak was not taken easily. There was no useful contemporary experience of its use other than in copies of old buildings or in renovation. The effect of the fissuring - as well as causing some wonderment about the variability of this hardwood - is to create 'instant age' and a rich variation in the surface texture.

The Study Centre was completed close to budget and programme, and opened in May 1994. It has since gained a good deal of praise both for its sensitive occupation of a difficult, prime site, and for the way in which it fulfils the demands of the brief (it won a RIBA Regional Award in 1994). The students enjoy the building: it has an informal, almost homely quality, which encourages use of the wide range of working environments that have been provided.

Credits

Client:
Darwin College Cambridge

Architect:
Jeremy Dixon & Edward Jones

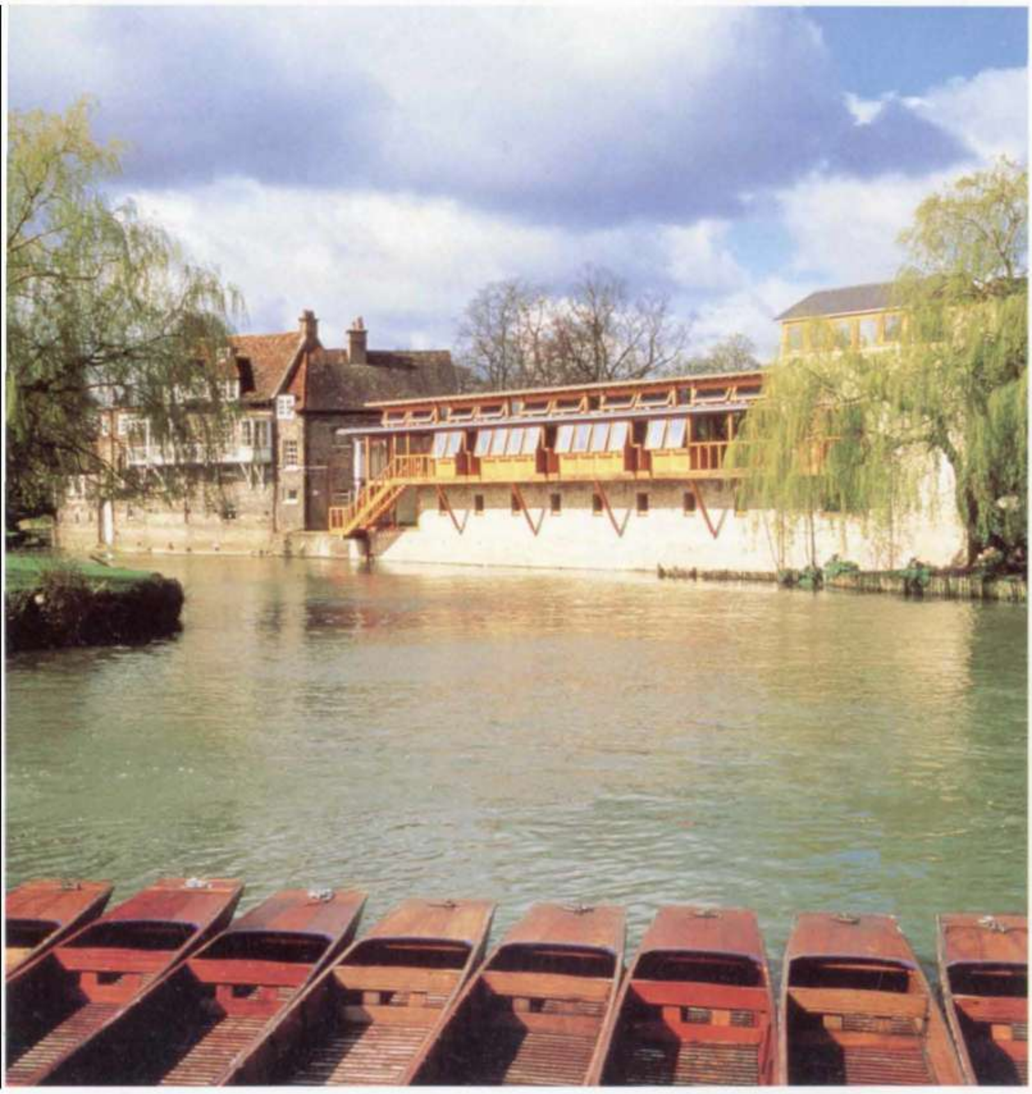
Consulting engineers:
Ove Arup & Partners Steve Blake, Simon Hancock, Roger Hyde, Lidia Johnson, Heather Marsden, Sarah Meldrum, Raf Orlowski, Stuart Redgard, Peter Ross, Mick White

Quantity surveyor:
Davis Langdon & Everest

Main contractor:
Rattee & Kett Ltd

Timber sub-contractor:
Henry Venables Ltd

Illustrations:
1, 2, 3, 5, 7, 8: D Gilbert
6: Dennis Kirtley/Trevor Slydel
4: Darren Sri-Tharam/Frank Pyle



8. The completed building in its riverside setting.

Hat Hill Sculpture Foundation

Roger Hyde

1

2

3

Introduction

Five years ago Wilfred and Jeanette Cass bought Hat Hill Copse House on 4ha of South Downs woodland in the grounds of the Goodwood Estate, West Sussex. Here they created a sculpture garden for their own and other contemporary works. The area is one of 'Outstanding Natural Beauty' - a beech plantation with dramatic vistas formed by avenues of trees - and their new informal visitors' centre and gallery has been carefully located between them to minimise tree removal. It is an uncluttered pavilion, with no shop, cafe, or WCs. Timber side walls form a visual link with the trees, while transparent east and west-facing end walls appear to bring the garden and sculptures into the building. To one side of the entrance there is a deep wall, copper-faced externally, which incorporates three video screens on the inside for visitor information, and storage for seating. On such a remarkable site, the building had to be special, unique, and due to limited budget and construction time: simple as well.

Strategy and structure

The design strategy was to separate clearly the elements and construction processes for foundations, superstructure, and finishes. The foundations were formed by continuous edge beams set at least 150mm into the underlying chalk to prevent root penetration, and linked by a ground-bearing slab which formed the floor of the building.

The structural concept stemmed from the client's need for $100m^2$ of column-free internal exhibition space and the design team's desire for a clearly expressed structural solution, as well as the need for speed. Steel was selected: a single central 'goalpost portal frame with external columns; on a north/south axis; this supports profiled-T roof purlins which cantilever beyond RHS perimeter supports to form canopies over the entrance and rear exhibition platform.

6

The timber side walls have steel frames cantilevering from the foundations, to allow the roof to 'float' above clerestory glazing. Stability is achieved through portal action and bracing in the steel framing to the side walls.

The roof has timber joists to support both its external deck and the plywood ceiling panels. A plywood web beam is inserted on the line of the central portal frame to collect and transfer lateral loads in the roof plane, avoiding the need for in-plane steel bracing but allowing maximum freedom for in-roof glazed areas. Various types of hardwood were considered for the side walls; birch-faced ply was selected for appearance, consistency with the materials being used internally, economy, and availability.

The approach to the design and detailing of the exposed steelwork was to seek quality through simplicity. Thus:

- The tapering T-sections were cut in pairs to minimise waste (and cost) from a standard 533 x 210mm UB section which allowed very slender cantilevers to be balanced against deep sections at the central portal.
- Ends were square cut.
- Bolted connections were used in preference to welding.
- No on-site welding was used.
- Exposed bolt heads were countersunk.
- The quality and line of cut edges and welds were agreed with the steelwork sub-contractor before fabrication commenced.

Conclusion

Prices for the steelwork were obtained prior to tenders for the main building. After appointment of the main contractor the foundations were quickly constructed; the steelwork was erected in one day, immediately followed by the roof which provided a shelter for the remaining works.

Construction was completed on programme within nine weeks, and to a very high standard of finished quality. The cost of £110 000 was inside the budget, and the building was opened in September 1994.

4

5

Credits

Client:
Mr & Mrs W R Cass, Hat Hill, West Sussex

Architect:
Studiodownie

Consulting engineers:
Ove Arup Partners
Jo da Silva, Roger Hyde, Edward Forwood

Quantity surveyor:
Davis Langdon & Everest

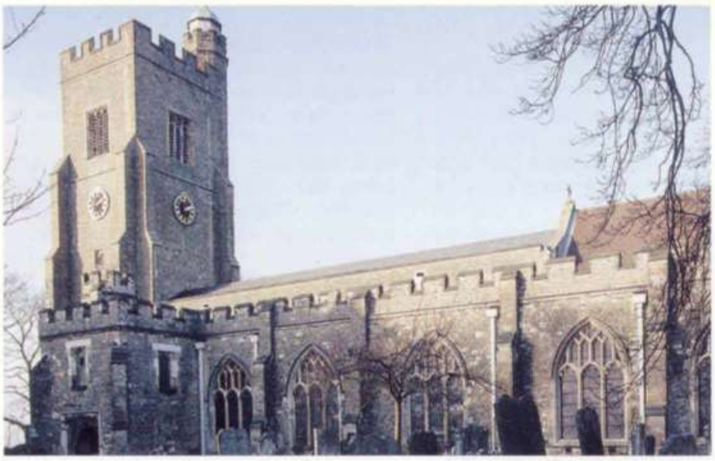
Main contractor:
J W Baker & Son (Chichester) Ltd

Steelwork contractor:
Allslade, Portsmouth

Illustrations:
1, 2, 4, 5: Katsuhisa Kida
3, 6: Peter Cook

St. Nicholas, Sevenoaks

Poul Beckmann
Peter Lunoe



1. St. Nicholas Parish Church.

Introduction

St. Nicholas' Parish Church, in the heart of the old town of Sevenoaks, Kent, dates in part from the 13th century, with additions until the 15th century when it reached its present size (Fig.1). It has an active congregation, who for over 20 years had been seeking to improve facilities; the existing parish hall was about 1km away, an awkward distance particularly for old people and young children. They wanted fully integrated accommodation: meeting rooms, refectory and a crèche directly linked to the church.

The problem was the impact of an addition to this historic building and environment. The church is surrounded by its old graveyard (any disturbance to which would concern local people), in turn ringed by buildings of Georgian or earlier date, several of them listed.

Feasibility

In 1988 the architect Robert Potter suggested an undercroft (Fig.2) - a habitable basement floor, and a more extensive space than a crypt, which usually underlies only part of a church. Arups' earlier work with Potter at All Souls Langham Place[1] and St. Stephen Walbrook helped to convince both the 'parish family' and the various advisory bodies that this bold proposal was not just feasible but also realistic.

The first step was to examine the ground stratigraphy and assess its suitability. A desk study was not enough: the church is surrounded by older buildings and there had been no recent site investigation nearby. It stands on a hill-top, so information from more remote sites, ie down the hill, would be of uncertain relevance. Three boreholes were sunk, to the immediate north, east and south. In addition, three trial pits were excavated to examine typical pier and wall foundations and two to assess the extent of archaeological remains, from interments or presumed earlier churches on the site.

The results were encouraging. The boreholes showed a reasonably constant stratigraphy across the site: 1-1.5m of made ground over medium-dense to dense, slightly clayey, sand to 13m depth, underlain by stiff clay (the Folkestone and Sandgate Beds), and then the weathered sandstone of the Hythe Beds. Groundwater levels in the Folkestone Beds showed seasonal variations but were generally at 11m below ground level.

The trial pits indicated that internal piers were founded on pad footings, typically about 1.7m square by 1m deep, bearing on the Folkestone Beds, whilst the north and south walls (and presumably the east wall) continued down with little if any spreading, again to the Folkestone Beds. Lack of spread footings to the walls - typically 800mm thick - may appear surprising, but the loads (self-weight plus small loads from the timber aisle roofs) are not great.

Visual examination of the church structure suggested that it was in good condition, with no significant cracks and no signs of distress or any structural problem. The regular quinquennial survey supported this view.

Arups' conclusion was that the ground stratigraphy was suitable to support both new structure and temporary works; and that the existing structure was in a sound enough condition for building a new undercroft immediately beneath.

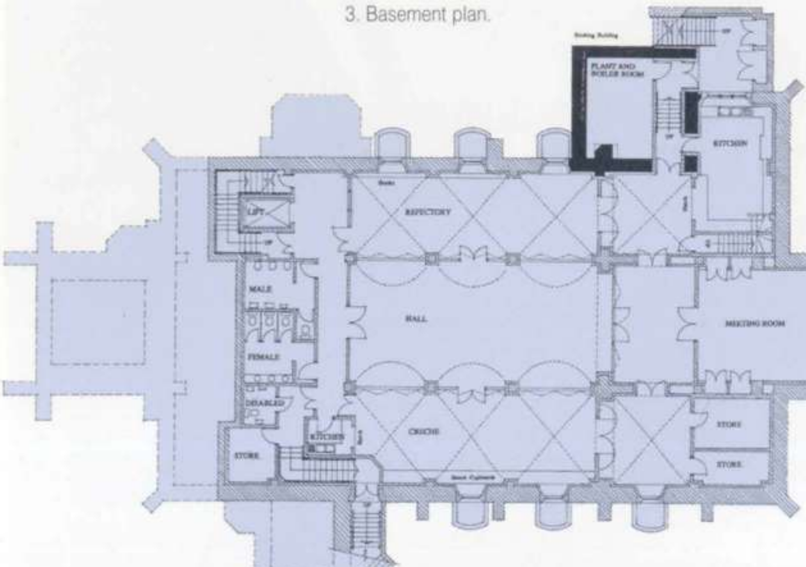
The scheme

The undercroft plan of 33m x 17m (Fig.3) would follow that of the church floor above, with the main and smaller meeting rooms beneath the nave and chancel. Refectory and kitchen would lie under the north aisle; the crêche and store rooms beneath the south. Sliding and folding doors would allow the meeting rooms to be amalgamated, separated, enlarged or reduced. The west end was to be avoided, so as not to disturb the more substantial foundations of the tower, let alone having to underpin them.

The new structure would have in situ concrete basement and ground floor slabs, side walls and internal columns. It would in effect form a box on which the church would sit.

2. Architect's cross-section.

3. Basement plan.



It had to be watertight, since rainwater permeates the surrounding ground. A vaulted plaster ceiling (Fig.4) would conceal ventilation ductwork and cabling.

The proposals were somewhat unconventional, and there was the expense of below-ground construction, so in 1991 the parish council examined options - 12 in all - from 'do nothing', through subterranean buildings in the grounds, to a complete undercroft. They concluded not only that the undercroft was the only solution which met the needs within the constraints, but that the costs could be met. In fact it has been entirely funded by donations from the parish family.

Approvals

Before tenders could be sought, let alone work commence on site, many approvals had to be obtained: from statutory bodies like local planners and the county archaeologist, advisory bodies such as English Heritage and the Georgian Society, and local interest groups like the Sevenoaks Society. Formal or tacit agreement was needed from all.

Not least, the parish family had to be shown that Arups' proposals both safeguarded the existing structure and were the best solution for achieving the desired integrated accommodation. Several meetings were thus arranged to present proposals and answer questions, some simple, others quite searching.

Finally, a Faculty - the formal diocesan approval for alterations to an ecclesiastical structure, its fixtures or fittings - had to be granted by the chancellor of the diocese, in this case after carefully examining the proposals. He also had to be satisfied with the parish council's business plan, since most funding was from covenants over a number of years; contractor's certified payments had to be met as the work progressed.

Methods

These had to be planned carefully - both with 'care' and 'fully'. The existing structure needed both vertical and lateral support through all temporary stages. Since it appeared to be in good condition, the first principle was to hold it in the same place throughout. Walls and piers were supported at shallow foundation level, so the second principle was to continue to support them just below ground level.

Each pier was to be held by an in situ concrete collar (Fig.5), with this supported vertically by piles and laterally by a grillage of beams. Pier loads would be transferred into the collar partly by grouted-in dowel bars in two directions, right through the pier plinth, and partly by trimming the plinth at a slight angle to form an inverted truncated pyramid. After excavation and basement slab construction, the underside of the pier plinth would be faced up, a new column built centrally under the pier, and the top 75mm drypacked. Just before drypacking, jacking with flat-jacks was proposed, not to raise the pier but to limit movements occurring as the load paths changed from the temporary to the permanent supports.

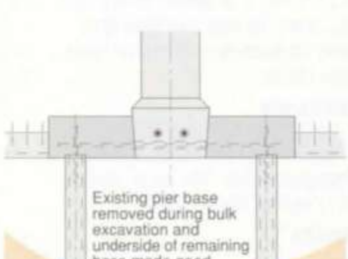
4. Completed main hall.

After considering several temporary support options, traditional underpinning was adopted for the north, east and south side walls. The 3.5m depth was quite substantial for these ground conditions, but a large advantage was that this work could be carried out from inside the church, avoiding disturbance to the graveyard. The outer part of the basement wall would be mass concrete underpins, in 1.5m maximum lengths on a 1-in-5 sequence, and the inner part in situ concrete, designed and detailed to normal good practice for watertight construction. Load eccentricity would occur when only the outer part was complete but not the inner, this being counteracted by a ground level beam integral with the beam grillage supporting the piers laterally.

One recurring (and structurally rewarding) feature was the way elements would meet various requirements during construction. For example, the beam grillage would provide lateral support to existing piers during excavation and construction, support to the side walls during underpinning, access routes for men and materials, and then support to the ground floor. The beams were designed for all these situations.

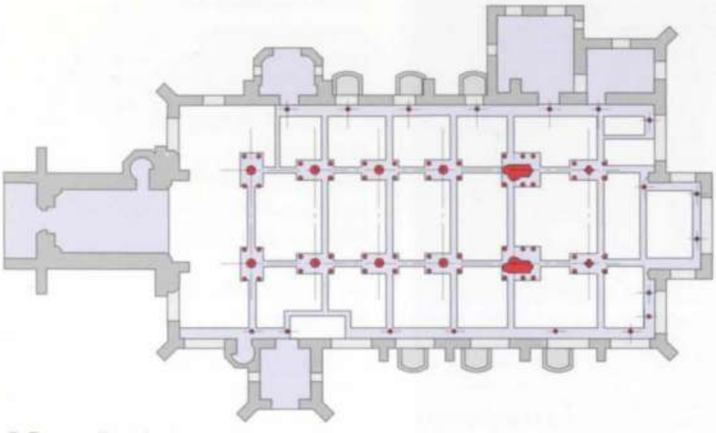
Contract

The project had been discussed well in advance with the tenderers, to ensure that the proposals and requirements were clear, to discuss practicalities, and to look at alternative ideas for construction methods. J. Longley & Sons submitted the lowest tender of £1 304 000, within the budget, plus an excellent method statement.



5. Collar to support pier.

6. Piling.



7. Beam grillage layout.

The earlier discussions were doubtless beneficial in achieving a satisfactory tender. Apart from a few details, Longley's proposed methods very much agreed with Arups'.

The contract, on a normal JCT 1980 basis plus some requirements particular to the project, was let in June 1993. The church was cleared and on 16 August Longleys took possession.

One particular contract condition was that the first three months be devoted to archaeological work and reverential removal of interments. The latter proved more extensive than anticipated, with up to five layers of burial in some places, and elsewhere unsuspected interments below already-known vaults.

A careful watch was kept on the foundations, about 1m below ground level, with adjacent vaults and burials up to 3m deep. Temporary struts were installed where deemed prudent. Monitoring stations were also installed at this time, to check existing piers and walls for level and tilt throughout the works.

Construction

On completion of the archaeological investigations, the ground inside the church was levelled and piling begun. All 69 piles were rotary duplex drilled using water flush, 220mm nominal diameter. Piles around piers had a working load of 200kN and were 14.5m long; those along the side walls to support the beam grillage had a working load of 120kN and were 10m long. All had central reinforcement bars to full depth, as normal for this type. The top 4.5m would be a free-standing column during excavation/construction and therefore had a 6m reinforcement cage, with a top dowel bar in lieu of the more normal projecting reinforcement to aid subsequent removal of the pile between the basement floor and ground level beams. Arups had previously established with the piling subcontractor, Keller Colcrete, that piles could actually be formed where planned (Fig.6).

The pier plinths were trimmed, diamond-drilled for the dowel bars, and the bars grouted in. The collars were cast and the beam grillage formed (Fig.7). East-west beams are concentric with piers, but north-south beams had to be offset: the piles which support these beams had to be offset to allow subsequent construction of sidewall columns which align with the piers.

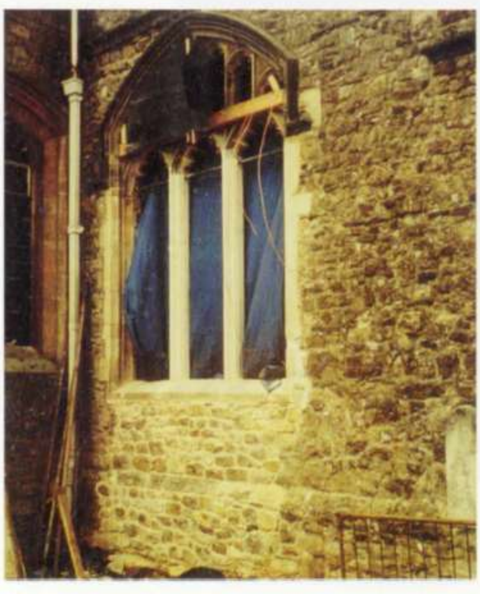
This illustrates another feature of this project, the inter-relationships between structural design and layouts, work sequence, and construction practicalities. In this case offsetting the north-south beams led to an advantage: the 7m-long central area beams became structurally more efficient because of their continuity with the side-span beams and so could be slimmed to just 250mm deep in the temporary stage, 400mm deep in the complete stage, thus improving the undercroft headroom.

8. Main excavation.

9. Underside of pier.

Fig.8 shows the stage when all Arups' planning was put to the key test: excavation. This is the same space as in Fig.4. Fig.9 shows the underside of a 14th century pier, with the supporting collar, beam grillage, and piles. The masonry foundations below the collars simply dropped away as excavation proceeded.

Excavation, sidewall underpinning, basement slab, inner sidewalls, columns, and ground floor slab proceeded at a good rate, considering access problems. The north-east window and wall panel below had been removed for access. Piling rigs and all other plant had gone in and come out through this opening. About 2500 m³ of excavated material exited here and was transported away - quite a logistical achievement given the narrow and busy roads. Fig.10 shows this window being reinstated.



10. Reinstated opening.

Completion

The undercroft was finished to a high quality, with lighting and audio systems to suit a wide range of uses. The church itself was completely re-ordered with a more welcoming ambience compared to the previous, rather sombre, style.

A gallery was added at the west end and a sacristy at the east end of the north aisle.

All work was complete in June 1995, and the church rededicated on 21 June. The parish family has welcomed its new facilities and many favourable comments have been made.

Reference

(1) BECKMANN, P and DEKANY, A. All Souls Langham Place and the Waldegrave Hall. *The Arup Journal*, *12*(1), pp2-8, March 1977.

Credits

Client:
The Rector and Parochial Church Council

Project manager:
Brig. Ian Dobbie

Architect:
Robert Potter in association with the Sarum Partnership Ltd

Structural engineers:
Ove Arup & Partners Poul Beckmann, Alan Chadwick, Derek Luby, Peter Lunoe, David Twine, Mel Wheeler, with help from many others on particular aspects

M & E engineers:
Peter Jay & Partners

Quantity surveyors:
Wilson Colbeck Partners

Main contractor:
James Longley & Co. Ltd

Illustrations:
1, 4, 6, 8-10: Poul Beckmann
2, 3: Sarum Partnership Ltd
5, 7: Trevor Slydel

A Shropshire Lad restored

Graham Scull

Introduction

Arups are known for large and prestigious projects world-wide. However, many small ventures are also undertaken, and one recently completed is the restoration of a statue in Shrewsbury, Shropshire, erected in 1816 as a tribute to Lord Hill, a well-respected local figure. Some 5.2m high, it stands on a 35.5m column - the largest single Doric column in the world. Column and statue are Grade II* listed and in the care of Shropshire County Council. Arups' advice regarding maintenance and repair was first sought in 1967, and again from 1992.

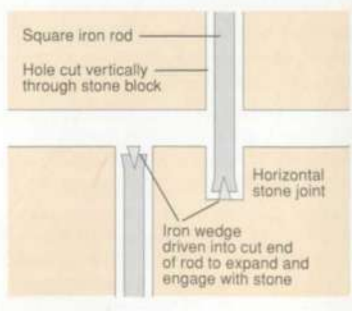
Historical context

Rowland Hill (1772-1842), or Viscount Hill of Almarez and Hawkstone Salop as he became, had a distinguished military career covering many campaigns, including Waterloo, and rose to Commander-in-Chief of the British Army. He also represented Shrewsbury in Parliament. The citizens of Shropshire raised £5972 by public subscription to build the monument, their esteem reflected in an inscription on the plinth: 'The inhabitants of the town and county of Salop have erected this column and statue, as a memorial of their respect and gratitude, to an illustrious contemporary, and an incitement to emulation in the heroes and patriots of future ages.'

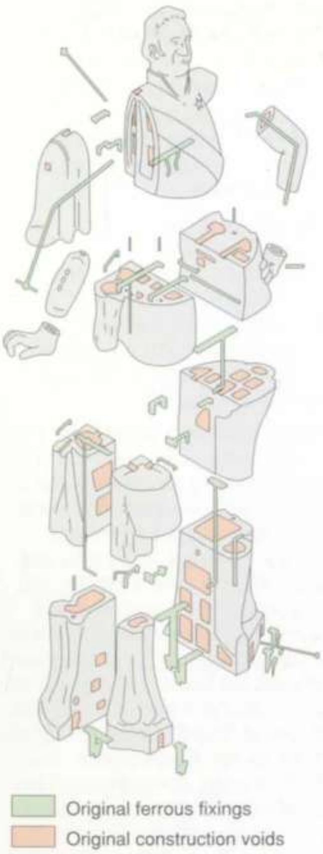
Construction

Column

The hollow column comprises 326 stone blocks with an average weight of 3.5 tonnes. Grinshill stone, a fine-grained, whitish-grey local sandstone, was used throughout, and construction must have been a major feat. John Straphen, the builder, donated the 172-step central spiral staircase, the cast iron balusters of which carry a commemorative inscription. Arups' recent investigations showed the column to be stable as a gravity structure except below the capital. The builders obviously realised this and installed wrought iron ties within the upper wall; an unusual lap detail was used for these ties (Fig.1).



1. Vertical ties in column stone.



2. Constituents of the statue.

Minor spalling from corrosion of this iron is present, but Arups concluded that no immediate remedial action was necessary.

Statue

The statue was built from an artificial stone manufactured from 1767-1843 by the Coade family of Lyme Regis. (later of Lambeth, London). Precise details of the blend are lost, but the British Museum Research Laboratory recently concluded that the main ingredients were ball clays blended with flint, quartz sand and a 'grog' of ground fired waste; the clay mix was moulded and then fired at 1000°C. Coade Stone's quality is such that an experienced eye has difficulty in distinguishing it from genuine stone, and it was used by many leading architects, including Adam and Nash.

The statue is thought to have been made in Lambeth and exhibited in London before being taken to Shrewsbury. It is believed to be the largest Coade statue in existence and is almost certainly in the most exposed location.

Earlier involvement

The original 1967 proposal was a glassfibre replica. However, Arups' calculations showed that the top of the column would become unstable with the reduced weight of the replica. This was a factor in the decision in the 1970s to undertake repairs to surface cracks and voids. Strong cementitious grouts and mortars were used; the right leg was replaced by a concrete replica; and at another time the right hand had also been replaced with a wooden copy, holding a replacement alloy sword. It is interesting to note the difference in attitude towards conservation which prevails today. Such replacements would not now be considered, and only sympathetic materials would be used for repairs.

Statue restoration

Since these repairs, further cracks had appeared and the Council were concerned for public safety. Arups were again appointed to ensure the stability and integrity of the statue. Investigations were made using radar and ultrasonics, but were inconclusive. After consultation with English Heritage it was decided to remove the statue from the column for repair. After cutting into sections (following the original joints as far as possible) and lowering to the ground, the full extent of the damage was realised. The statue was found to have been built from a number of hollow sections and an armature of wrought iron ties and straps had been used to stabilise the various parts (Fig.2).

The voids to the lower sections had been filled with a brick and lime mortar during construction, while upper voids were filled with the later cementitious grout. Over the years moisture had penetrated, and expansive corrosion of the armature had caused severe cracking of the Coade shell from within.

A specialist contractor was engaged with extensive experience in both Coade Stone and statue restoration. The statue's condition dictated that it could not be repaired on site and so it was moved to the contractor's yard in south-east London. The client, contractor, English Heritage, and Arups met on a number of occasions to develop a solution acceptable in both engineering and conservation terms.

3. The statue in its fractured state.

One of the prime aims of restoration was that it should be reversible if further work was found necessary by future generations. Arups determined that tension could develop in the joints under wind loading so a stainless steel armature was designed to prevent this and tie the various parts together. Voids in the Coade shell were cleared of all fill and iron parts, and cracks were repaired with resin-anchored stainless steel pins.

The voids were refilled with new pieces of brick set in lime mortar, holes were cored and rebates cut to take the new armature, and special ties were detailed to fix the arms and concrete leg in place.

4, 5.
Right and below:
After restoration.

Conclusion

After being away from Shrewsbury for over a year Lord Hill was replaced on his column in autumn 1995. Apart from stainless steel, the materials used were those available at the time of original construction. This was a rewarding project for the team, who had participated in developing a solution to a unique problem. Satisfaction also comes from knowing that the statue should now continue to be a monument to Lord Hill for many decades to come.

Credits

Client:
The Director of Environment, Shropshire County Council

Principal contractor:
Taylor Pearce Restoration Services Ltd

Consulting engineers:
Ove Arup & Partners
Graham Scull, Michael Bussell

Illustrations
1: Trevor Slydel 2: Matt Nation, Taylor Pearce Restoration Services Ltd
3: Graham Scull 4: Shropshire CC
5: Images UK Shrewsbury

The M4 Relief Road

Robin O'Brien
Simon Witney

Introduction

The M4 in Wales is the Principality's only length of motorway. It extends for 125km across the south - passing near the main urban centres of Newport, Cardiff and Swansea - links with England across the Severn Bridge, and is an important artery in the European network because of its ultimate link with Ireland via Fishguard. The Welsh Office consider the M4 to be the most crucial part of the road network in Wales, improvements to which have aided the Welsh economy by providing access to markets, helping to attract inward investors, and improving tourist accessibility.

The problem

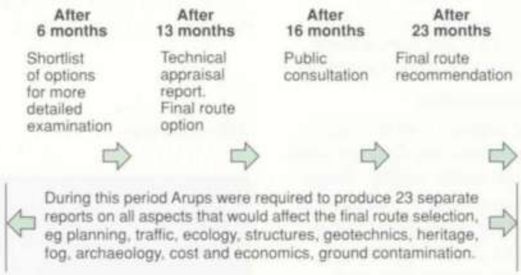
In early 1989, the Secretary of State for Wales commissioned the South Wales Area Traffic Study (SWATS) to review traffic patterns on the area's major roads. The section between Magor and Castleton was identified as a potential problem area by the study. A solution was clearly needed in the next decade; if action was not taken, road journeys into Wales would become increasingly slow, unpredictable, and frustrating. The area would become less attractive for business, leading to loss of job opportunities.

Most measures were already in hand: the Brynglas Tunnels scheme was designed to relieve the most congested section of the M4 for traffic into Newport; and the Second Severn Crossing (SSC) would reduce flows on the existing bridge by 70% when it opens to traffic in 1996. The SWATS study, however, confirmed the need for a more strategic solution to meet long-term requirements over the 27km section between Castleton, east of Cardiff, and Magor, where the link with SSC would meet the existing motorway.

The M4 where it runs through Newport's northern suburbs carries more traffic than adjacent lengths (there are seven junctions in 21km) because it is joined by two trunk roads from the north (A449 and A4042) and the A48(M), feeding from the south. In addition, several principal routes join it within a short distance. It is predicted that between now and early next century traffic congestion will occur along this length of motorway.

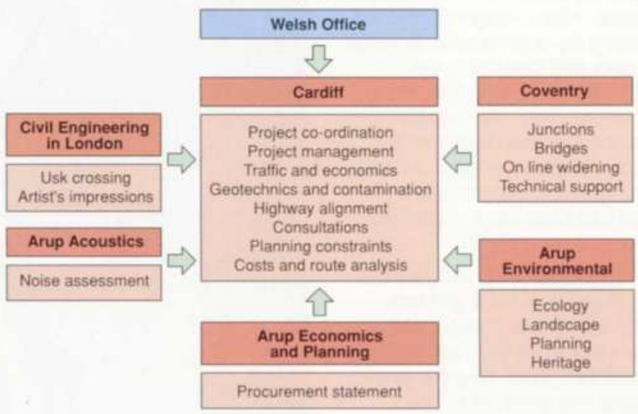
After considering the SWATS findings, the Secretary of State added an M4 Relief Road to the Welsh roads programme, with construction to start around the turn of the century. Arups were appointed in January 1992 following a 'Stage 1' fee bid tender (lump sum). This was in line with Welsh Office procedure which splits schemes into three stages:

- Stage 1:
  feasibility and route selection
- Stage 2:
  design and public inquiry
- Stage 3:
  construction.



1. Arups' commission: 'Find a route for the M4 Relief Road'.

2. The project team.



There is no doubt that the Welsh Office were attracted by the advantages of a locally-based and managed team backed up by multidisciplinary resources.

Not only did Arups already have the right experience and personnel, they already know the study area well and most key officers in the local authorities.

Three main 'themes' were proposed as part of the bid:

(1) A local team with a single line of communication between the two project managers, with every item of correspondence and report sent by the Project Manager

(2) The local team would benefit from the wider Arup capacity in the UK in the form of assistance from other offices.

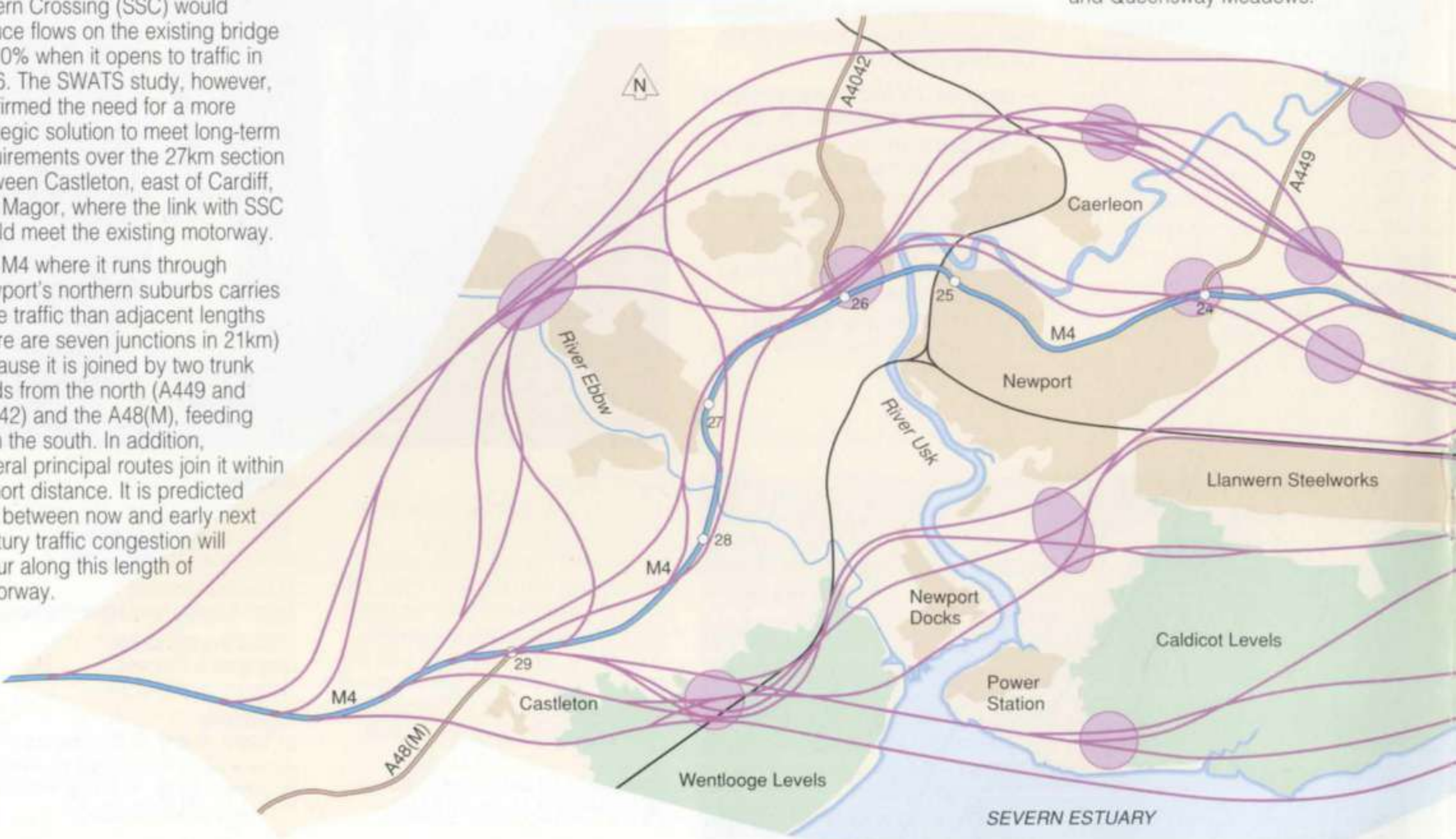
(3) At key milestones during the study, decisions would be reviewed by an Arup review panel consisting of senior representatives from London, Coventry and Cardiff.

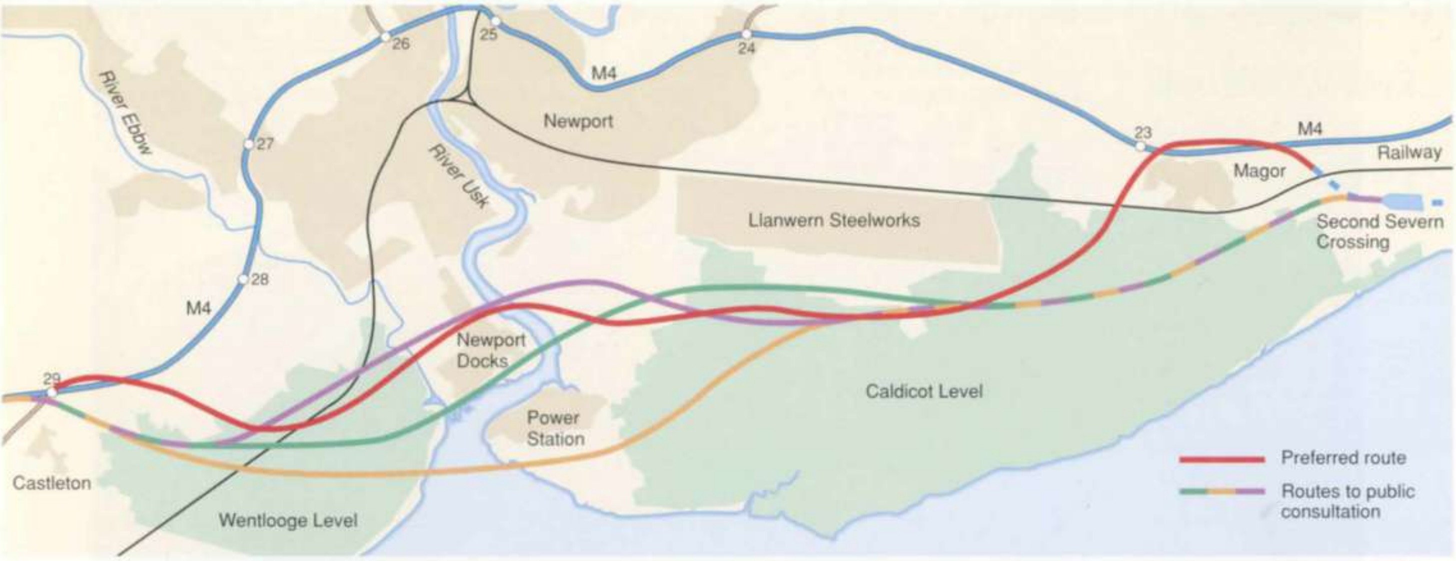
The study area

Though Arups' brief covered 50 typed pages, the task was simply to find a route within the 280km² study area, within which the Welsh Office had given the widest possible scope by including land up to 5km away from the existing M4.

Most of south east Wales is typically 'rolling' countryside, crossed by river valleys creating a number of steep escarpments. The main river is the Usk; it flows roughly north/south through the centre of the area and drains into the Severn Estuary, an area protected by European and international law in view of its importance for wildlife. The low-lying area between the Severn Estuary and the higher ground in the north are Sites of Special Scientific Interest (SSSIs), known as the 'Gwent Levels'. The most important communication link actually crossing the Levels is the main railway between England and Wales, a highly prominent feature in the west of the area.

The study area is thus one of two district contrasts divided by the existing M4, which roughly follows the northern extremity of the Levels, although well elevated and often separated from them by development. This includes Newport (population 82 000), Newport Docks, the British Steel Works at Llanwern which employs 3500, Uskmouth Power Station, and more recent commercial development at Duffryn and Queensway Meadows.





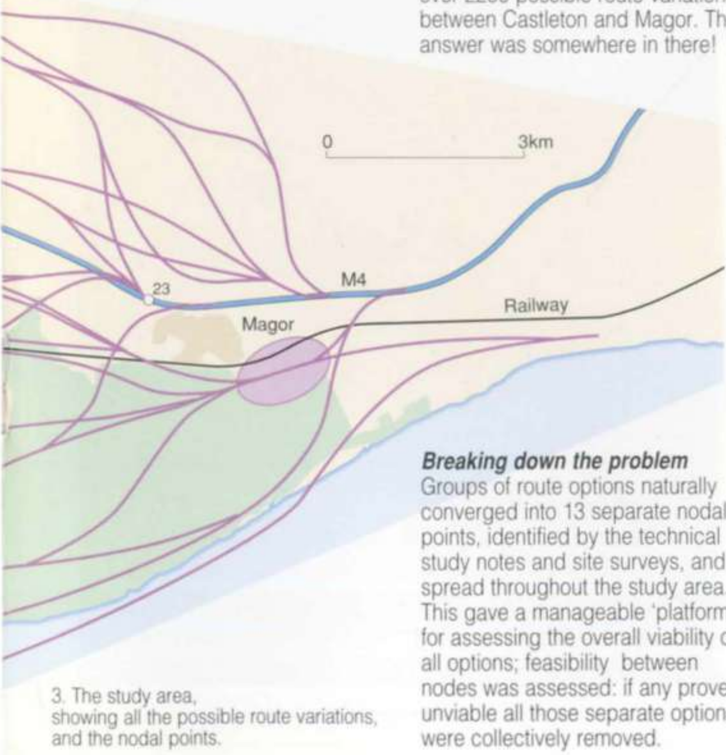
The Levels themselves are given over to agriculture, with only a small population in scattered villages.

North of the M4 are important highway links within the valleys, and some large linear settlements, particularly to the west. The higher ground between the valleys remains open and attractive, with pockets of woodland and a network of footpaths.

The 2nd Augustan Roman legion was based at Isca, one of only two such bases in Wales. Caerleon, on the banks of the Usk north of Newport, has the historic remains of Isca, one of the best-known archaeological sites in the country, with the best-preserved Roman amphitheatre.

Route selection

Any preferred route has to withstand the rigours of public inquiry, and will fail if a lucid and thorough selective process, based on a clear understanding of the motorway's potential impact on people and the environment, cannot be demonstrated.



3. The study area, showing all the possible route variations, and the nodal points.

Background data

The study started with a wide-ranging but high-speed data collection exercise. Topographical information was based on Ordnance Survey digital data, loaded onto Arups' Intergraph system. To help appreciate the study area's main features, this was supplemented by a low-level aircraft flight for the design team.

As well as the main technical reports required by the client, a system of study notes was used to review and analyse the collected information and provide a baseline for technical assessment. Over 30 were produced, covering subjects like flooding risk, shipping impact in the Usk, hydrology, wind effects, the Severn Barrage projects, and tunnelling schemes designed to avoid long river bridges.

How many routes are there?

Given the minimum geometric requirements for a new motorway and avoiding obvious 'no go' areas like urban centres, the team examined every feasible option, in all over 2200 possible route variations between Castleton and Magor. The answer was somewhere in there!

Breaking down the problem

Groups of route options naturally converged into 13 separate nodal points, identified by the technical study notes and site surveys, and spread throughout the study area. This gave a manageable 'platform' for assessing the overall viability of all options; feasibility between nodes was assessed: if any proved unviable all those separate options were collectively removed.

4. Above:
The three public consultation routes and the preferred route, incorporating the changed alignments at each end.

Initial assessment

This was made under four headings:

Traffic: how far did options go in meeting objectives and how attractive were the various junction alternatives?

Environment: what degree of overall impact would there be?

Engineering: geotechnical and infrastructure difficulties

Costs.

An important feature of the assessment was commonality of approach, giving engineering and environment equal weight in the process, and avoiding the difficulty of mixing quantitative and qualitative appraisals.

The shortlist

Arups recommended five options to the Welsh Office for fully detailed technical appraisal, four to the south of the existing M4 and one to the north. Although there are understandable concerns about crossing the Gwent Levels, the impact of northern options was assessed as higher in terms of noise, heritage, planning, and the built environment: almost all were therefore rejected.

Detailed technical appraisal

Detailed alignment plans were prepared for the five shortlisted routes so that full technical appraisals could be made. Traffic, planning and environment, cost and economics, hydrology, and drainage criteria were further assessed, enabling the team to identify a final choice of routes for public scrutiny and wide consultation. Public involvement was seen both by Arups and the client as vital in the whole selection process. The views of local people, whether directly affected by the scheme or not, are needed before any decision is made. Similarly, any viable scheme has to be more than just an imposed engineering solution, it must be acceptable as part of the future planning and development of the area.

Consultation

For a scheme this size, consultation was no small undertaking. In July 1993 Arups sought views on the three most southerly options, consulting all 44 local authorities and representatives, 55 transport and environmental groups, and 40 other bodies - from British Coal to the Youth Hostels Association.

Secondly, arrangements were made for the public (160 000 in the study area) to look at the options, ask questions, and complete questionnaires. For optimum response, details were delivered to 10 000 homes in the area.

Thirdly, the data had to be assimilable and analysable, so a project-specific data base on Filemaker Pro was set up in house. As a result of public responses to this first consultation, a second was undertaken in September 1994, on alternative alignments at each end of the route.

Results

The M4 Relief Road, as the only 'greenfield' motorway now proposed in the UK, understandably generated a great deal of concern and considerable opposition.

Friends of the Earth and the pressure group 'Save our Severnside' were very active, and most public response was unfavourable, principally on environmental grounds.

However, the scheme was widely supported by local planning authorities who saw its construction as essential to South Wales' future economic prosperity.

Taking both this and the local concerns, where possible, into account, Arups recommended a final route to the Welsh Office.

The preferred route

This is quite clearly a balance between the competing interests of nature conservation and development, whilst meeting the scheme objectives. It was officially announced as the 'preferred route' by William Hague, the Secretary of State for Wales, on 12 July 1995. At 24km, it is shorter than the 27km existing motorway and will cost £320M to build. *Concludes on page 27*

5. Superimposition of the preferred route through Newport Docks.

The River Usk and its crossing

The Usk rises in Central Wales and reaches the sea at Newport. It flows for the majority of its length through attractive and unspoilt valleys, and is important for its scenic qualities, its historic and literary associations, and its game fishing (salmon and trout). It is also a tidal river for many kilometres inland, draining into the Severn Estuary which has the second highest tidal range in the world. It was also the basis for Newport's growth in the 19th century as a dock town, as its name suggests. To this day, shipping and associated businesses like warehousing and distribution form a large part of the town's employment and industrial acreage. Although this base is declining, new commercial and retail businesses are replacing the traditional riverside industries. For these reasons, and the fact that the mouth of the Usk is of international importance for wildlife, the Relief Road has been designed to cross it in a way which will minimise the impact on navigation and the active industries within the dock and alongside the river. There are many challenges awaiting the bridge designer, including long span forms to accommodate shipping needs and satisfy visual demands, and complex foundations through an old dockside.

Gwent Levels and the historic landscape

The Gwent Levels (comprising the Caldicot Levels to the east of the River Usk and the Wentlooge Levels to the west) are generally the result of salt marsh and fenland reclamation in historic times. The existing M4 in fact roughly follows the original shoreline.Although there is evidence to suggest that the Levels supported scattered Iron Age and Bronze Age settlements, they were reclaimed principally during Roman times. The Severn Estuary coastline has since been allowed to advance, during the late Medieval period, leaving a legacy of low, flat (under 5m) pastureland and meadows, with scattered settlements.

Various historic features still remain, such as moated sites, duck decoy ponds and earthworks of former manor houses. Further excavations to be undertaken during the course of the environmental assessment for the Relief Road are almost certain to reveal further finds of archaeological importance. Agriculture - generally dairy farming - is still the main use of the Levels. Except where they were part of ecclesiastical holdings, they developed a character unique in Britain. Following land enclosure in the 14th-19th centuries, a distinctive pattern emerged, with open fields divided by deep, generally straight, watercourses and ditches called 'reens', and smaller field ditches.

These are often complemented by hedges or bankside vegetation. The system of drainage is highly complex and sensitive to hydrological changes, eg flow rate and direction, contamination or water level - all matters to be taken into account in the assessment of and detailed design for the Relief Road. The intricate network of reens and field ditches has given rise to the creation of particularly valuable natural habitats, notably for wetland plants and animals. In fact, the ecological significance of the reens is so great that the Levels are comprehensively protected as a series of Sites of Special Scientific Interest stretching virtually uninterrupted from Cardiff to Caldicot. The Severn Estuary itself is also a SSSI.

6. Reens are the major feature of the Gwent Levels.

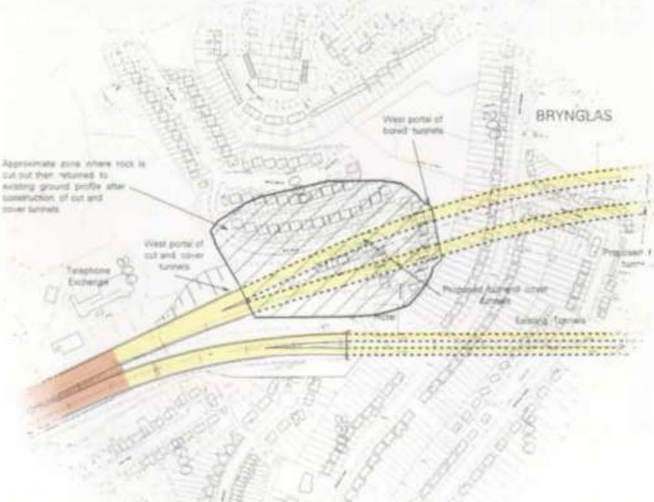
Planning and development

In choosing an alignment for the M4 Relief Road, Arups had to take into account the representations of Gwent County and Newport Borough Councils. Both have favoured regenerating Newport Docks, and retaining operational land required by British Steel at Llanwern Steelworks to the east of Newport - South Wales' largest employer. Further, because of the area's relatively high unemployment, Newport Borough Council has indicated its intention to encourage development to the west of the town, into the Wentlooge Levels. These planning constraints and development aspirations were weighed against the strong conservation policies which apply to the Gwent Levels, and an alignment preferred for the Relief Road which drew a compromise between encroaching too far into areas either protected or earmarked for development.

7.
Aerial view of British Steel plant with preferred route superimposed.

On line widening

Traffic congestion on England's motorway network is being tackled through a programme of widening[1]. The possibility of widening the existing M4 'on line' between Castleton and Magor was examined in great detail, as the problem is essentially local to Newport, between Junctions 23 and 29, rather than a matter of congestion along the whole corridor. On line widening offered considerable advantages - no impact on the Gwent Levels and restriction of noise and visual intrusion to the existing motorway corridor. Despite this, Arups concluded that it should be rejected as an option: it would require over 200 homes to be demolished, would need to be constructed to lower standards, and would cause substantial disruption during construction. This all added up to a very poor economic performance.
The urban nature of the existing motorway made widening unviable on the scale needed to solve the problem.



8. Example of on line widening detail.

▼ *Text continued from page 25*

Despite passing through and close to developed areas the road will require the demolition of only four properties. Also Arups managed to restrict impact on the Gwent Levels by selecting a route along the northern edge of the protected areas. A high proportion of the scheme cost is in the structures. 26 new bridges will be needed, the main structure being a new bridge to cross the River Usk and Newport Docks area. This could be 4km long and account for nearly half the total cost.

Comment

Planning new highways often takes a long time, so two years between the original commission and selection of a preferred route is relatively quick. Even so, in this time the debate about road building, transport systems, and sustainability has moved on. To give the client current advice by keeping abreast of changing issues is a major challenge in a high profile route selection study. The Arup team, working very closely with the Welsh Office Project Manager, was able to reflect current concerns and issues in delivering a preferred route, so that the decision is 'up-to-date' even if the original objectives have not changed.

The next stage

Arups' commission was completed when the preferred route was announced. Although later than originally thought (due to the second consultation), reporting fully the technical appraisals and the options took 75 reports in 32 months - acknowledged by the Welsh Office as a tremendous team effort. The Welsh Office has now invited bids from four consultants for the next design stage (Stage 2). Arups are involved and intend to offer the same strengths that won the first stage.

Reference

(1) HALL, P *et al.* Motorway widening projects. *The Arup Journal*, *29*(4), pp.10-15, 4/1995.

Credits

Client:
The Welsh Office

Consulting Engineers:
Ove Arup & Partners Tom Armour, Kambis Ayoubkhani, Mark Bostock, Nigel Cogger, Ed Colgan, Mike Edmonds, Fred English, Graham Good, Sophie Greaves, Mike Hayes, Dick Hensby, Ed Humphreys, Ginny Hyde, Simon Lawrence, Paul Johnson, John Mabbett, Iain McCulloch, Glyn Morris, Robin O'Brien, Sylvia O'Brien, Peter Richardson, Janette Shaw, Nick Sidhu, Ian Statham, Richard Thomas, Gabe Treharne, Chris Tucker, Duncan Wilkinson

Sub-contractors:
ESL (Environmental surveys)
BTO (Ornithology)
ELP (Marine experts)

Illustrations:
1-4: Glyn Morris/Denis Kirtley
5: Marshalls/Wood Visual Communications/Nigel Whale
6: ESL
7: The Welsh Office/Gwent Industrial Photography/Nigel Whale
8: Ordnance Survey/Ove Arup & Partners

British Airways Avionics Facility

Chris Jofeh

1. The site during construction.

Introduction

British Airways (BA) has made significant investments in South Wales in recent years. Servicing large aircraft fleets efficiently is big business and after careful research BA decided that Wales was the right location. First was the engine maintenance facility at Nantgarw, near Caerphilly. Arups came on the scene with Project Dragonfly, the triple jumbo jet maintenance hangar at Cardiff's Rhoose Airport, for which the Cardiff office were design team leader, engineers, architect, and contract administrator[1].

In November 1991 Percy Thomas Partnership were appointed by BA as architects, and Arups' Cardiff office were appointed as engineers for the new avionics (aviation electronics) facility at Llantrisant, near Cardiff, which maintains all the electronic components that are essential for modern aircraft: radios, radar, flight instruments, accelerometers, gyroscopes and so on, as well as catering equipment. BA decided to turn the need to service their electronics into a business opportunity by creating a world-class facility which would also attract business from other airlines. They have succeeded in this aim.

The Welsh Development Agency(WDA) has an excellent record in promoting inward investment in Wales and in attracting high technology industries to replace the old industries that have withered away. The Llantrisant site chosen by BA was already under development by the WDA to provide several desirable business sites in this key location in a lovely wooded valley, close to the M4.

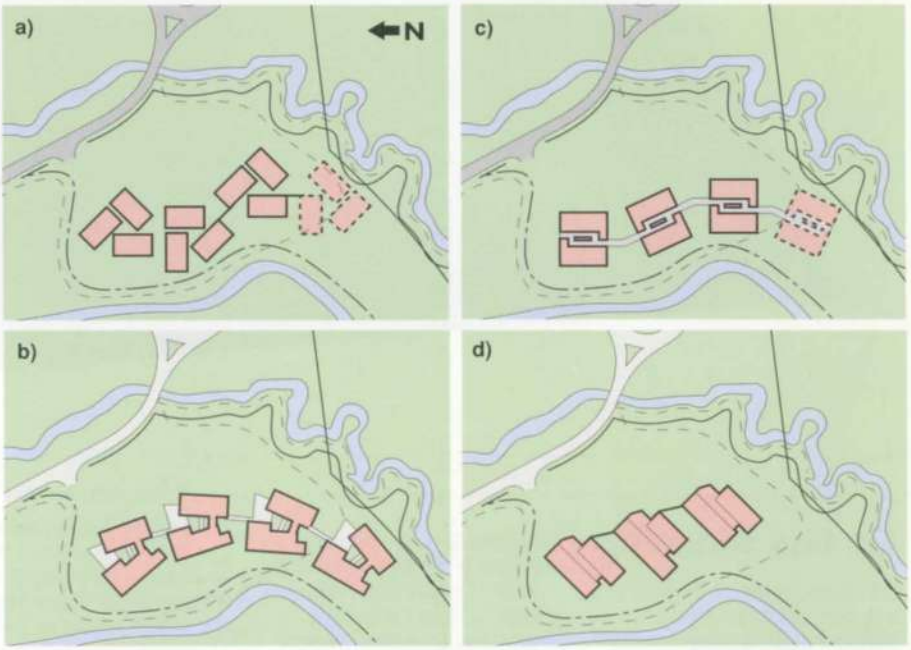
The brief and the architecture

The client wanted a purpose-built, highly-serviced facility that simultaneously met B1 commercial criteria for net-to-gross floor area ratio, floor-to-floor height, energy efficiency, single or multiple tenancy, and servicing flexibility. One special feature of the brief was delivery times of electronic components from store to workshop: 80% within three minutes and 100% within 15 minutes of the request being keyed in by a technician at a computer terminal in a workshop. As a benchmark, at BA's previous facility at Heathrow delivery times were usually measured in hours and sometimes days.

There is a sound business reason for this aspect of the brief: planes do not earn money while they are sitting on the ground.

A series of design team workshops involving architects, engineers, quantity surveyors, BA's property branch, and the users generated common goals that were accepted commercially and technically. From these emerged three primary design strategies, known as the 'doughnut', the 'wedge', and the 'cluster'. These were further refined using value engineering techniques to demonstrate that the chosen design solution met the agreed goals most effectively. Fig.2 shows some of the 42 layouts that were analysed.

In plan (Fig.3) the chosen design solution resembles Eric Parry's building W3 at Stockley Park[2]. However, it developed as the most appropriate response to the brief and the site and not as a copy of an attractive building. There are three silver-clad, two-storey buildings organised along a sinuous layout that reflects the natural shape of the plateau. Each building meets B1 planning criteria, providing space suitable for specific office and workshop activities. The three buildings have a total floor area of 13 000m², and the site planning provides for a fourth building as business grows. The workshops (Fig.4) are simple 18m-wide rectangles in plan, either side of a tapered atrium space (Fig.5) that provides support facilities: reception, cloakrooms, coffee shop, restaurant and lecture theatre. There are major plantrooms (Fig.6) within the distinctive curved roofs, and minor plantrooms at each end of the floors.

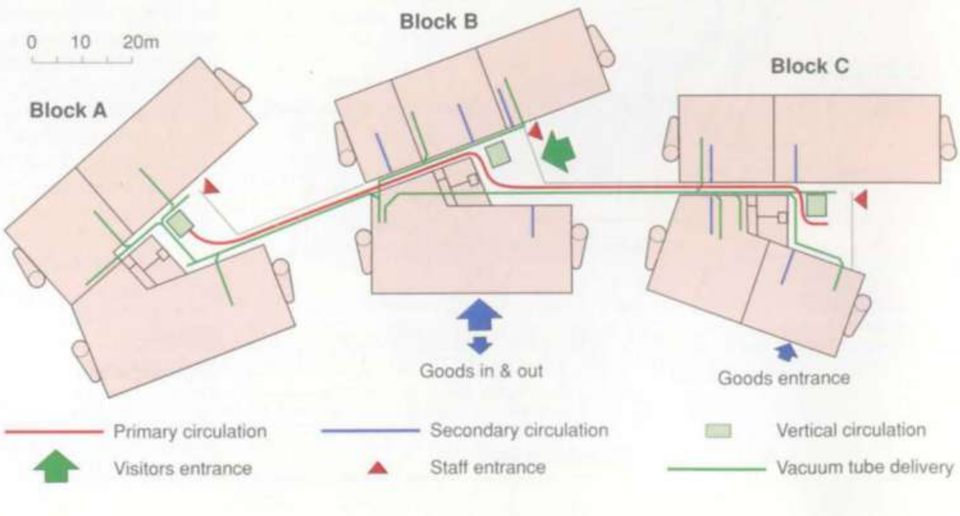


2. Some of the 42 options considered: a) Cluster, b) Wedge, c)+d) Doughnuts

The site and the geotechnics

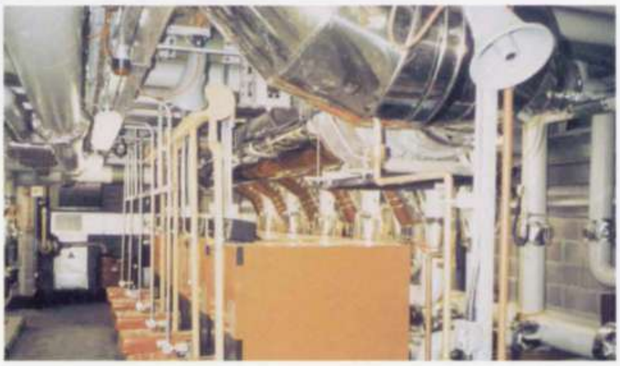
The site is a man-made plateau between the rivers Ely and Nant Muchudd at Ynys y Plwm, north-west of Cardiff (Fig.1). Because electronics and water do not mix happily, the top of the plateau was set 0.5m above the predicted 1 in 10 000 year flood level. It consists of about 3-5m of imported fill, resting on 0.9-1.6m of alluvium, beneath which are medium dense and dense sands, gravel and coarse gravel. Some peat deposits were found in the alluvium.

3. Site plan.



5. Above: The atrium restaurant.

4. Above: Interior of workshop, with pneumatic tube in foreground.



6. Plantroom.

The WDA's plateau engineers had anticipated that buildings here would be founded on piles but Arups' geotechnical engineers were able to demonstrate that piles could be omitted if the peat pockets were removed. This was done and the buildings were founded simply and economically on shallow spread footings. The plateau was not complete by the time construction of the Avionics Facility began. Arups advised the WDA and their engineers of where the leading edge of the plateau needed to be to avoid settlement problems caused by filling too close to a building. This was done and there were no problems.

The structure

The design team examined 10 possible structural schemes and four column grids, from which they chose lightweight concrete on profiled metal decking acting compositely with steel beams spanning onto columns on a 9m grid; stability is provided by braced frames sized so as not to clash with windows or doors. This was simple, fast, economical, adaptable, and well-suited for close integration with the extensive building services. Profiled metal decking is also used in the roof, to brace the top flanges of the curved beams, to supply in-plane distribution of lateral forces, and to provide a safe working platform for the roof cladding.

Although the structure is simple it is special in a number of ways. Experience in Arups' Los Angeles office had demonstrated significant advantages in US West Coast structural detailing and this was adopted for the Avionics Facility. This involved the use of typical structural details which provided the steelwork fabricator all the information he needed for all the connections. The steelwork and the metal decking were fully detailed before the job was tendered, necessary to ensure a flying start to meet the tight programme. The steelwork design allowed the fabricator the choice of whether or not to weld some connections on site; in the event he chose to do so. Typical details were also provided at tender time for the foundations, ground slabs, cladding support steelwork and blockwork.

Once the main contractor was appointed and he had appointed his steelwork fabricator, the designers and builders began a period of close collaboration to ensure a rapid and trouble-free fabrication drawing process. Every Monday Arups' engineers met the steelwork fabricator in the offices of the main contractor. There Arups previewed the fabrication drawings, answered the fabricator's questions and responded to his suggestions. This meant that virtually all the fabrication drawings submitted to Arups for approval were given Status A first time around. It also helped develop a good working relationship based on trust and mutual respect.

Building services

An early design goal was to make the greatest possible use of daylight and natural ventilation. Deep floor plans, internal heat gains, and the very demanding warranty conditions of some items of test equipment, meant that it was also necessary to provide mechanical ventilation, comfort cooling, general air-conditioning, and very close control of both temperature and humidity in some areas. A particular requirement of the avionics engineers was the avoidance, if reasonably practicable, of all piped services in the ceiling spaces. Some workshops also needed to control the amount of dust in the air.

The electronics workshops have extensive electrical needs: a high degree of reliability of supply; uninterruptible supply for key test equipment, computers, and life safety; an illumination level of 750 lux; 415V/240V 50Hz; 200V/115V 400 Hz ; 28V DC; clean earth; static earthing; data and communications cabling; public address; fire alarm and detection; lightning protection; and security. The workshops also required compressed air at 100psi and 3000psi, vacuum, helium, nitrogen and carbon dioxide.

Sprinklers were required in the central store and in computer areas. Fig.7 shows a typical matrix of what services were required in the different production units (PUs) of one of the buildings. Each building was to be self-contained to enable it to be sold if that met a future need of the avionics business.

Incoming electrical services to the site are supplied at high voltage to three external sub-stations, one per building. These feed a low voltage switch room on the ground floor of each building.

The main plantrooms in the roof space contain boilers (Fig.6), chillers, pumps, and primary air handlers.

7. Servicing matrix.

Small Block

	Special vent	Suspended floor	Inertia bases	Static (humidity)	Natural vent	Special A/C	General A/C - C/C	Compressed air	Vacuum local units	Helium/Nitrogen	Other special	415V/240V 50Hz	200V/115V 400Hz	28V DC	Clean earth supply	Static earth
Ground																
PU2	●				●			●		●	[illegible]	●	●	●		
First																
PU11	●	●		●			●	●	●		●	●	●	●	●	●
PU12	●	●		●			●	●			●	●	●	●	●	●

Large Block

	Special vent	Suspended floor	Inertia bases	Static (humidity)	Natural vent	Special A/C	General A/C - C/C	Compressed air	Vacuum local units	Helium/Nitrogen	Other special	415V/240V 50Hz	200V/115V 400Hz	28V DC	Clean earth supply	Static earth
Ground																
SU2	●				●			●				●				
PU1	●	●	●		●			●		●		●	●	●		
First																
PU9	●	●		●			●	●	●			●	●	●	●	●
PU6	●	●		●			●	●				●	●	●	●	●
PU7	●	●		●			●	●				●	●	●	●	●

8. Exterior, showing blue risers and atrium shading.

These supply air via external risers (Fig.8) to large close control room air-conditioners at the ends of the floors, which supply, recirculate and filter, cool, heat, and humidify the air as necessary. Mixing of primary and recirculated air occurs at a ratio of approximately 1:8. Air is delivered and extracted by ductwork in the ceiling voids.

Primary air is filtered to limit the amount of dust supplied; filters in the close control units remove dust that may have entered the workshops by other routes, such as inside the packing cases containing parts to be repaired.

Because of the large number of engineering systems involved, the ceiling void was carefully zoned so as to discipline its use by different trades (Fig.9). As a result no services clashes were reported during construction.

A 150mm raised floor contains all electrical and communications cabling, again carefully zoned to make the best possible use of the space. Local distribution is via purpose-designed multi-compartment bench trunking.

The 28V DC supplies are provided by numerous local transformer rectifier units mounted on the workbenches, whilst the 400Hz supplies are from static inverter sets in the low voltage switch rooms.

Arup Communications (AC) worked closely with BA's Information Management (IM) group to assess the requirements for IT. AC identified the impact of IT on space provision within the buildings, from the depth of the underfloor zone to the layout of equipment in the equipment rooms. Analysis of BA's resilience requirements led to the adoption of dual routing for all external cables.

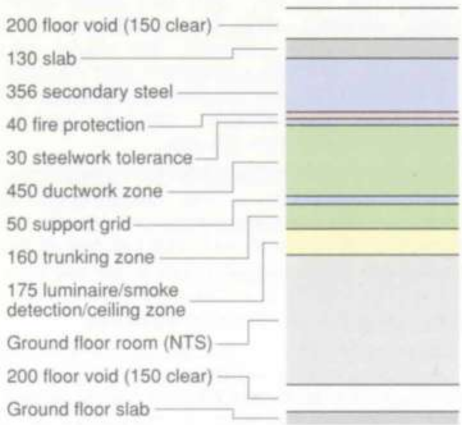
Materials handling

The avionics business at Heathrow maintained 66 000 airborne components per annum across 12 000 product lines from over 600 suppliers, with a breakdown stock level of 2.5M parts.

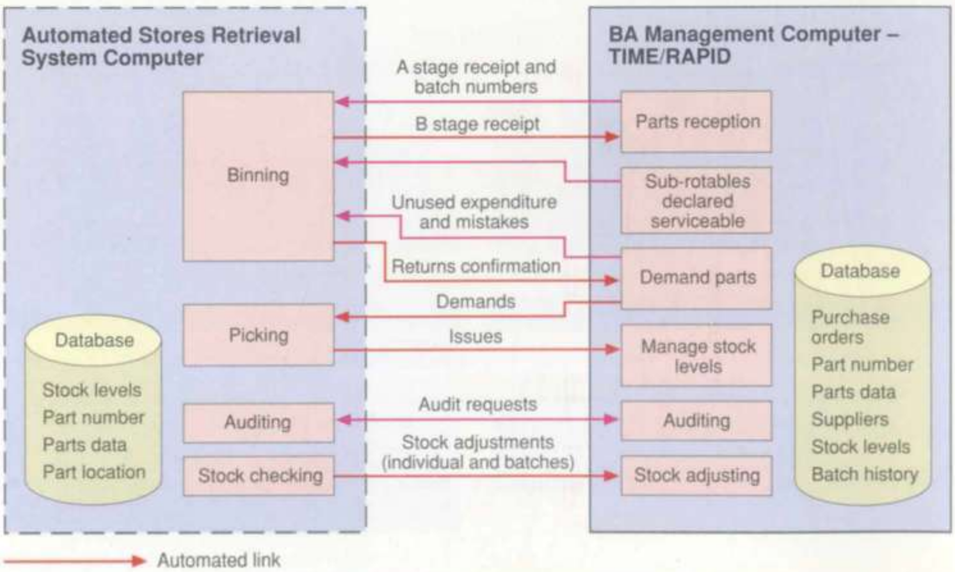
British Airways Avionic Engineering (BAAE) identified four key materials handling strategies in support of their mission to become global leaders in avionics engineering:

- Internal component turnaround time to be reduced to three days.
- Component throughput to increase from 66 000 to 130 000 per annum.
- Breakdown spares holding not to exceed six months' usage.
- Overheads to be minimised wherever possible.

9. Service zones for typical floor.



10. Materials handling software interface.



Arups carried out studies of possible storage and distribution systems that could satisfy the 80% in three minutes and 100% in 15 minutes requirements. These included:

- central versus regional versus local stores
- manual versus automated stores.

The following storage options were considered:

- horizontal carousels
- vertical carousels
- compact storage
- high bay automatic stacking and retrieval

... and the following distribution systems:

- hand/trolley
- manual vehicle
- automatic guided vehicle
- conveyor
- monorail

Arups recommended a strategy comprising:

- central automatic high bay storage and retrieval system (ASRS)
- manual forward (local) stores for bulky items like circuit cards, accelerometers and gyroscopes
- distribution of rotables (airborne components) by hand
- distribution of large spares by hand
- distribution of small spares by pneumatic tube.

This was then subjected to a value engineering analysis which recommended that a cost benefit study be carried out to compare an automated and a manual central store. The analysis showed both operational benefits and lower costs for the automated store and it was chosen for further development.

Part orders for breakdown spares are generated by technicians in the workshops and transmitted via a wide area network (Fig.10) to materials management software at Heathrow, which then processes the order and sends an instruction back to the ASRS. In the two-storey tall central store (Fig.11) high speed computer-driven robot cranes travel along two aisles storing and retrieving parts from over 2000 storage locations. Special algorithms ensure that frequently needed spares are stored near the front.

One of the robot cranes retrieves the box containing the spares and places it on a small conveyor belt which in turn delivers it to one of the two human operators, who in turn sends the spare via the pneumatic tube system to the workshop. The ASRS computer maintains accurate records of the history of all its airborne components to satisfy Civil Aviation Authority (CAA) and Federal Aviation Authority (FAA) requirements for traceability.

The system delivers spare parts to 17 locations throughout the facility 24 hours a day, 365 days per year with a system availability of better than 97% including downtime for maintenance. It is designed to cope with call rates (requests for spares) of up to 7000 per week and 18 per five-minute peak. AEG was the specialist sub-contractor, chosen in competition after an exhaustive evaluation.

Arups' Cardiff office carried out all the feasibility and preliminary costing work through to system definition and value engineering. Arups in London prepared the performance specification and then managed the production of the functional specification, which was a collaborative effort by AEG, BAAE and BA's IM group.

Summary

- November 1991: Design team appointed.
- June 1992: Main contract out to tender.
- August 1992: Main contractor appointed.
- September 1992: Construction of first block begins, with the second and third blocks following at three-month intervals.
- May 1994: Third block handed over.
- November 1993: BAAE began moving in.
- December 1993: CAA certification.
- January 1994: FAA certification.

The facility received a 1995 RIBA Regional Award for Architecture in Wales, and was commended in the commercial category of the 1995 Lighting Design Awards by the Lighting Industry Federation. Over 350 people are now employed there and business has grown faster than predicted. At the opening ceremony on 15 December 1993, Mr ACD Cumming, managing director of British Airways Engineering, unveiled a plaque which contained a motto for the new facility. Written by the children of a nearby primary school, Ysgol Gynradd Gymraeg, it reads 'O'r Cymoedd i'r Cymylau', which translates as 'From the valleys to the clouds'.

References

(1) LUKE, S *et al.* British Airways Project Dragonfly. *The Arup Journal, 28*(3), pp.8-15, 1993.

(2) Mind over machine: New building at Stockley Park. *Architects' Journal, 194*(18), pp.44-65, 30 October 1991.

Credits

Client:
British Airways plc

Client project managers:
British Airways Property Branch, Property Construction Group

Owners of shell and core:
Welsh Development Agency

Architect:
Percy Thomas Partnership

Consulting engineer:
Ove Arup & Partners Steve Chewins, Russell Jones, Tony Larcombe, Anna Rooney, Ian Statham, Kevin Wood (civil)
Simon Adams, Pavel Bartos, Caroline Burt, Phil Coomer, Mike Cronley, Chris Jofeh, David Kane, Eddie King, Karen Lloyd, John Lovell, Mark McElligott, Peter Monkley, Diane Sadleir, Gareth Stewart (RE), David Thomas (structural)
Christina Button, Dylan Evans, Daniel Goodreid, Jonathan Griffiths, Wendy Hoare, Chris Lynn, Phil Nedin, Mike O'Grady (RE), Geraint Rowlands, Brett Seeney, Ian Stuart, Karen Winder (building services)
Tim Brooke, Emre Serpen (materials handling)
Stephen Pollard, Sam Shemie, Priscilla Tang (communications)
Rob Harris (Arup Acoustics)
Karen Hull, Donna White (administration)

Quantity surveyor:
Bucknall Austin plc

Programming advice to BA:
Andrew Garbutt Management

Main contractor:
Laing South West

Steelwork subcontractor:
Dyer of Oxford

Mechanical and electrical subcontractor:
Matthew Hall

Materials handling subcontractor:
AEG

Cladding subcontractor:
Hathaway

Illustrations:
1: Gareth Stewart
2, 3, 7, 9, 10: Trevor Slydel
4, 5, 8, 11: Peter Mackinven
6: Brett Seeney

11. Left:
Interior of materials handling area, showing racking, one of the cranes and the pneumatic tube delivery system.

Dublin Civic Offices, Phase 2

Kevin Dolan Ian Roberts

Origins

The Wood Quay site on the south bank of the Liffey has obvious advantages: it is centrally located near City Hall, the Mansion House and Government buildings, and close to the original Viking settlements and perhaps even earlier dwellings.

The nearby Ford of the Hurdles (Baile Atha Cliath in Irish) was the principal river crossing and gives its alternative name to Dublin or Dubh Linn (Black Pool). Wood Quay contains a series of revetment walls - marking increased river channelling for deeper vessels - and part of Dublin City Wall, built in 1100. It is one of the most important urban archaeological sites in Europe.

Phase 1

There had been many proposals for Civic Offices from the turn of the century onwards. In the 1960s, an international design competition was held, and won by Stephenson Gibney & Associates with Don Keoghan & Partners as consulting engineers, but it was 1973 before construction commenced.

The scheme was dogged by difficulties and controversy, because of its impact on archaeology and for its design, which gave rise to extreme critical reaction on both sides. Dublin Corporation felt that new ideas were needed for Phase 2, to benefit from developments in office design since the 1970s. Clearly, it would be influenced by the first design as well as remaining archaeology on the site, and another factor was the delicate stonework of nearby Christ Church Cathedral: any development had to avoid dominating it.

Phase 2 competition

In 1992 the Corporation held an architectural competition for Phase 2. By September a short-list of eight practices had been drawn up, including Scott Tallon Walker with Ove Arup & Partners Ireland as civil and structural consultants. The teams were given a month to complete their schemes, which were then examined by the international jury. On 10 December 1992 Scott Tallon Walker were awarded the commission and instructed to prepare working details for a site start on 7 April 1993 with completion by July 1994.

This article is a shortened version of a paper given to the Institution of Engineers of Ireland and the Republic of Ireland Branch of the Institution of Structural Engineers on 3 October 1994. It was awarded a Smith Testimonial by the IEI and the 1995 Branch Prize by the ISE.

1. Above: Block 4, Phase 2, from the Liffey. On the left, the garden atrium connects it to Block 2, with the Block 1 tower visible beyond.

The brief

There were three principal requirements:

- parking and office space
- the construction timetable to meet tax incentive deadlines
- the influence of archaeology.

12 500 m² of office space were needed, with the usual ancillary spaces, public areas, and 330 car spaces. The new scheme required delicate integration into the existing buildings so that user functions were synthesised efficiently. Construction time was influenced by Government incentives giving tax relief on rentals provided buildings were started and completed before certain dates.

At competition stage these incentives were in place - and particularly attractive.

The archaeological influence was threefold:

- The building site was generally confined to areas that had already been examined.
- A large central area was to be reserved for public open space, and to preserve the archaeology below.
- Any work in previously undisturbed areas would be subject to scrutiny.

Concept design

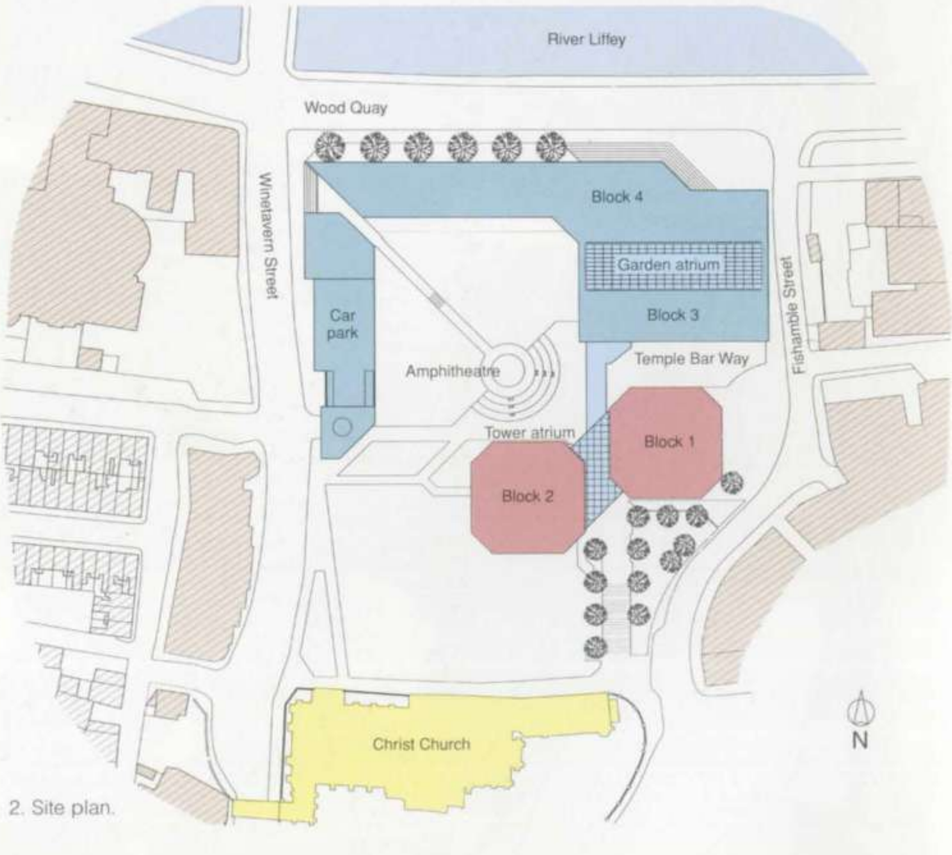
The site is U-shaped, covering an area used for car parking and already excavated to the basement level of Phase 1 (Blocks 1 and 2). Access is via a ramp at Winetavern Street.

There are two basement car parking levels with two office blocks (3 and 4 - six and five storeys high respectively) built above, parallel to the river.

Each is on a 7.2m square grid to match the standard parking bays underneath, giving an ideal 14.4m overall width of office space.

Blocks 1 and 2 suffered from a lack of high level links and from the harsh environment between them. Both Phases are now connected by a three-storey glazed link building over a pedestrian route linking Temple Bar Way into the public open space and amphitheatre.

This route also follows the old Viking city wall and leads to a museum housing a history of the site and part of the wall. The new focal point of the development is the space between Blocks 3 and 4, which are linked by a fully glazed atrium containing mature tropical trees and bridges at each level between the blocks.



2. Site plan.

Site investigation

Fill, river silts, and gravels overlying fractured calp limestone rock were revealed. The rock levels (the controlling parameter for foundation design) sloped steeply from existing basement level to 5m deeper at the river side of the site.

There also proved to be groundwater in the gravels - and only partially river water, which would be significant when considering the building's energy requirements.

Groundwater energy

As the scheme developed, consideration was given to reducing energy costs. Dr. Tim Cooper, at Trinity College Dublin, demonstrated that heat in groundwater could be used to feed heat pumps cost-effectively, and it was also known that such water was available in the gravel under Dublin. The only questions were how much was under the site, and what was the river's influence?

Phase I included building a retaining wall round the site along Wood Quay, Fishamble Street and Winetavern Street, its 5m wide mass concrete base transferred the retaining wall loads to the rock.

A convenient side-effect of this was to isolate the site from the river water regime. Tests confirmed that new site-drilled wells provided a pure water supply at an almost constant temperature of 11°C, subsequently proved to yield more than the sustained 12 litres/sec required for the system.

Three wells were sunk to rock level at -5m OD and connected by gravel drains. Cost analysis indicates that the pump system will initially break even and should produce savings in the long term.

Archaeological dig

Much of the site had been completely excavated in 1973-1976, but one section to be built upon remained unexplored. The tax deadline time constraints left 12 weeks for a substantial and important dig. Up to 10 archaeologists worked on the site, uncovering large areas of revetment wall, the old City Wall and the remains of several houses, all helping to build an image of Dublin some 900 years ago. Items found in this and previous digs are to be housed in the new museum.

Basement concept

The existing basement level, below the general water table, requires continuous pumping to avoid flooding. At competition stage the high cost of a water-tight basement became apparent, and any means of avoiding it was an advantage. Since 1976 relatively modest pumping had been effective, and as the area was only used for car parking, it was decided to have a conventional ground-bearing lower basement slab. To minimise damage should water levels rise, land drains were installed, with pressure relief chambers at regular intervals.

Foundations

Block 4 was founded on 100-tonne capacity, 300mm diameter, reinforced grouted bored piles with a 3m rock socket, this length determined by shear strengths of $30N/m^2$ for limestone and $5N/m^2$ for the mudstone/siltstone inter-layers. Although the piles are generally short, their use aided the quick programme and the archaeological dig, while minimising groundwater control problems.

The rock formation was within 3m of Block 3's lower basement level, so pad foundations with an allowable bearing pressure of $500kN/m^2$ were used. This avoided excessive rock excavation and formation preparation, given the calcareous mudstone veins in the dark grey argillaceous slatey limestone.

Settlement calculations were carried out along the interface of the piled/pad footing foundations, to ensure differential settlements were maintained within acceptable limits.

Existing retaining wall

Following the coring to rock through the 5m deep mass concrete base under the existing Wood Quay wall, areas of cement wash out were discovered, stemming from difficulties in placing the concrete during Phase 1. Its loadbearing capacity was doubtful, so where new columns were incorporated in the existing foundations it was necessary to core and grout the existing structure to accommodate the concentrated loads. Two 120mm diameter cores, each reinforced with a T40 bar, were provided at each column location with the base straddling between piles and the grouted base.

Floor plates

Blocks 1 and 2 have a 7.5m structural grid with 3.5m floor-to-floor height throughout, except for the car park levels where it is 2.725m. For Phase 2 the architects detailed a 1.2m horizontal module within the 7.2m x 7.2m grid, and a 1.166m vertical module. The perimeter columns were then set back from the edges, giving a final grid of 7.2m x 6.6m above ground floor level. The brief specified a 150mm raised access floor and a 350mm service zone for possible future mechanical ventilation. In response to these constraints and the rapid building programme, a 300mm flat slab was selected, which proved an economical solution. An important feature was the absence of downstands: perimeter beams to support cladding attract load and transfer structural deflection into cladding movement joints, becoming large, disruptive elements in an otherwise simple solution. This was avoided by providing 140mm thick, 1.2m deep, 7.2m long precast panels.

The floors in both blocks were completed in two weeks through increasing the cement content to $370kg/m^3$; this gave early strengths, reducing backpropping requirements to one level and allowing following trades earlier start dates. The limitation on service openings in flat slabs was overcome by locating all vertical services distribution near the stair cores. As these are set into the 7.2m grid it allowed a short end span of 3.6m. This zone was designed with reinforcement grouped to provide 1m x 1m soft zones with a 150 mm deep infill section that could be removed or omitted as required. Similarly, reinforcement for core stability was provided at the ends of the walls. This aided lateral distribution of services and door openings through the central portions of the core walls.

There were some variations, including areas for compactor shelving, atrium planters, and Fire Brigade access to Temple Bar Way between Blocks 1 and 3. The former did not need a raised access floor. Thus the increased imposed loads were accommodated by increased reinforcement in a 375mm slab and encasing the shelving rails in a 75mm screed. The 1.2m high atrium planters were accommodated using upstand beams and two-way spanning slabs.

Vertical structure

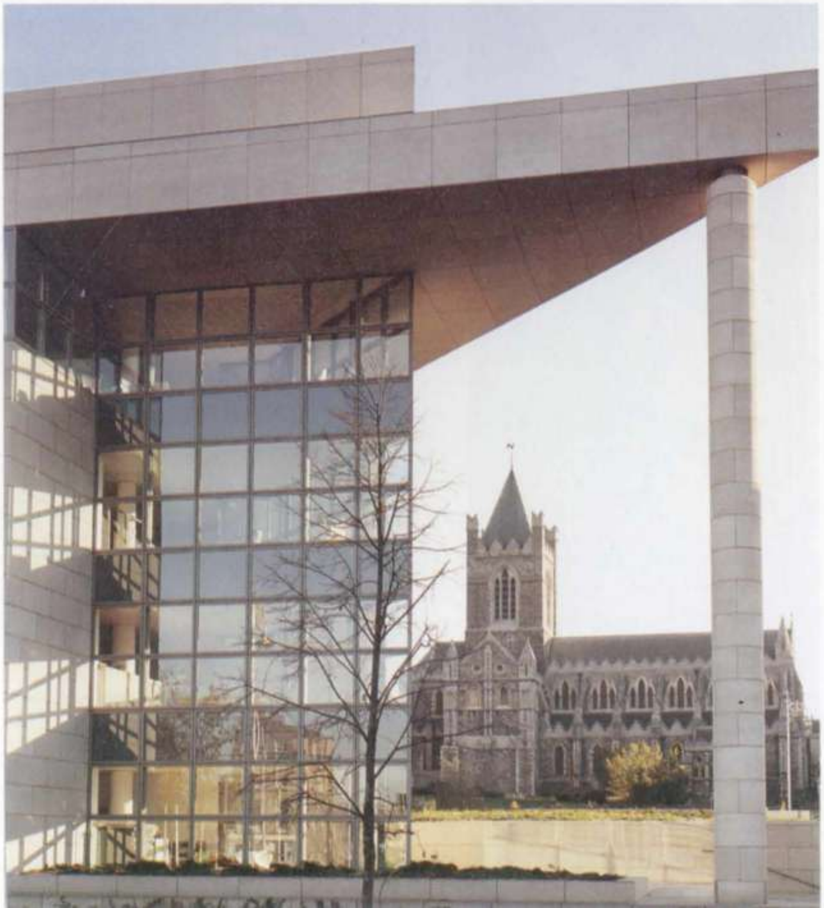
Overall stability derives from the five stair/lift cores with in situ reinforced concrete walls. The floor plates act as diaphragms between cores with *Stafix* dowels to transmit horizontal and vertical shears at the central expansion joint.

Columns are circular, from 300 mm - 600 mm, and frequently contain rainwater pipes. To give consistency of size at each side of the atrium and to avoid the dominating effect of large columns some were constructed in composite form, using universal column sections cast in concrete. Cardboard forms were used for shuttering and when removed allowed for a plaster finish.

The four-storey high portico at Wood Quay is supported by 580mm wide duo-decagon concrete columns with Portland stone surround. Initially, solid prestressed stone was considered, but was rejected on cost grounds.

Roofs

These generally are similar to the floor slabs. The exterior of the top floor penthouse roof is composite steel/concrete on metal deck to reduce local loads on the floor below. Plantroom roofs use metal deck on steelwork beams to falls. At the west end (by Winetavern Street) the parapet forms a 21m-span, deep concrete beam to maintain the view of Christ Church Cathedral from the river. Similar beams span 14.4m at the main entrance to maximise column spacing and reduce their crowding effect.



3. North-west corner of Block 4, with Christ Church Cathedral in the distance.

Cladding

The building is clad with 40mm thick granite and 70mm thick Portland stone parapets and soffits. Portland stone highlights step-back features to the elevations where balconies were introduced. All stone was site hand-fixed to dense masonry blockwork, precast concrete spandrel panels, or concrete walls. The architect wanted no joints more than 6mm, including vertical movement joints. Detailed considerations of probable movements, however, indicated a joint width of 12mm per storey height, so relieving angles were introduced at half-storey height (1.75 m).

Horizontally, stone is fixed to 7.2m long spandrel panels supported close to the columns and restrained at their centres. The panel fixings allow movement vertically and horizontally, including plumbness. Having fixings only at the ends prevents slab movements being transferred into the movement joints of the stone, thus minimising joint size.

Garden atrium

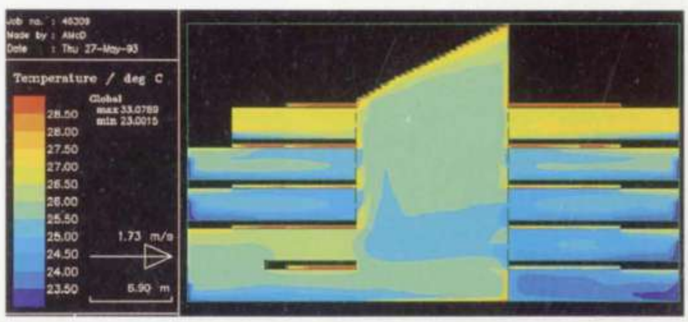
The atrium exists not only to form a civic area between Blocks 3 and 4 but to give the equivalent of external walls within internal space; maximum transparency and thus minimum structure were required, as well as visual interest. Conventional trusses or beams looked clumsy, whilst spaceframes, with their high levels of redundancy, would appear cluttered. The solution was to maximise the number of tension elements and confine compression elements to areas already sized to take glazing bars. The resulting trusses, spanning the 14.4m between Blocks 3 and 4, take the form of the bending moment diagram with tension members following an overall curved shape. For inward wind pressure the 114mm tubular glazing support members take compressive forces and 20mm rods the tension; the curved shape and rigid joints eliminate diagonals.

4. (and 5. below left): Aspects of the garden atrium.

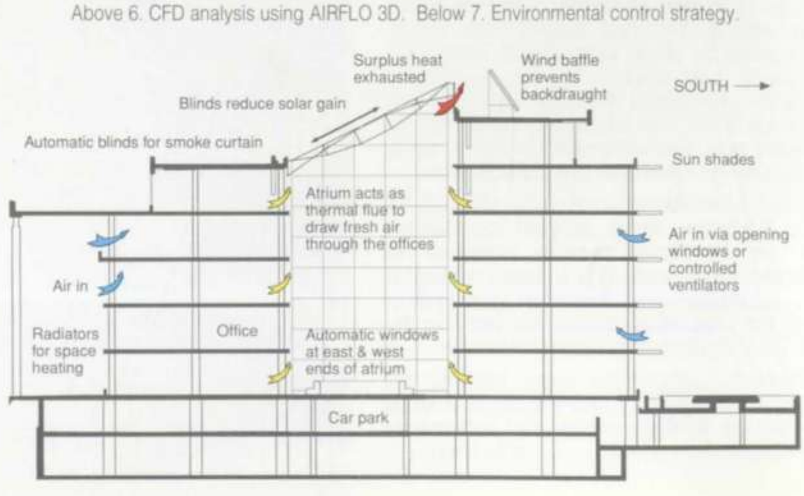
Environmental control

Current office standards and energy costs dictate a preference for natural ventilation. The atrium gave a means of ventilating the offices by the natural properties of rising warm air, balanced by vents to draw outside air over the ceiling, and a temperature-sensitive control system.

Arups in London analysed the spaces using their ROOM and AIRFLO 3D programs to predict internal air temperatures and velocities. With these they were able to highlight problem areas, and advise on the size and location of windows, vents, partitions, shading devices, etc.



Above 6. CFD analysis using AIRFLO 3D. Below 7. Environmental control strategy.



For outward wind pressure there is effectively no compression member so pairs of 12mm catenary bars are provided. Machined forked end connector couplers were used to connect the rods to the struts, which allowed fine tuning of the structure on site.

The bridges between Blocks 3 and 4, and their stairs, required delicate treatment to maintain the lightweight open feeling in this public area. Steel beams with thin concrete infill on permanent metal deck were used, the overall structural depth being kept to 275mm for the 14.4m span using a tension system of diagonal rods supporting both the bridges and the half-landing of the stair flight below. Dummy links give the impression of connection between flights but in fact each set of bridge and stairs is structurally separated. Glass balustrades are provided at all edges.

Work to existing buildings

As one objective of Phase 2 was to unify the whole, joining Blocks 1 and 2 with a new glazed atrium necessarily fell within the scheme. This series of 13.2m long, 1.32m deep trusses in circular hollow steel was fabricated in pairs, with 76.1mm tubular tie infilling between units for lateral stability. The bolted joints have site-welded cover plates. In the new atrium the existing blocks were interconnected with composite steel/concrete bridges at two upper levels.

Other developments in Blocks 1 and 2 included the provision of a creche, canteen extension, computer room, and museum, which encloses part of the original City Wall and archaeological artifacts from the site. The circular amphitheatre in the central park area provides a focal point to the pedestrian routes linking Temple Bar and the Quays.

Handover was on 29 July 1994 in accordance with the competition requirements, 16 months after start on site and 21 months from the start of the competition. Final construction cost is of the order of IR£15 m.

The building has received considerable critical acclaim, including praise from its original critics. It has recently gained the Association of Consulting Engineers of Ireland Award for Excellence in Structures and the Irish Construction Industry Federation Award for Building Excellence.

Credits

Client:
The Lord Mayor, Alderman and Burgesses of the City of Dublin.

Architects:
Scott Tallon Walker

Civil & structural engineers:
Ove Arup & Partners Ireland Frank Callanan, Sami Dahdouh, Phelim Devine, Kevin Dolan, Kieran Dowdall, Jim Hughes, Eamonn Judge, Terry O'Riordan, Ian Roberts, Conor Roche, Maeve Sookram

Environmental design:
Ove Arup & Partners [London] Tom Barker, Andrew McDowell

Mechanical & electrical engineers:
Varming Mulcahy Reilly Associates

Quantity surveyors:
Bruce Shaw Partnership

Fire engineers:
Michael Slattery & Associates

Main contractor:
Pierse Contracting Ltd

Cladding sub-contractor:
Irish Portland Stone, Breton Roecrete and Stone Developments Ltd

Structural steelwork sub-contractor:
Andrew Mannion Ltd

Illustrations:
1, 3-5: Norton Associates
2, 6, 7: Ove Arup & Partners Ireland

Turner's Glasshouse restoration, National Botanic Garden, Dublin

Gerard Duffy Ralph McGuckin

Introduction

From the 16th century, increasing world trade brought many exotic plants to Europe. Glasshouses became a *sine qua non* for all serious plant collectors and styles varied from utilitarian hothouses to the 'architectural' orangery. Interest in botany flourished and in 1815 Sir George MacKenzie published his ideal glasshouse design - a south-facing quarter sphere. His thinking was that, to minimise reflection, the sun's rays should be able to strike the glass perpendicularly at all times of day, summer and winter. This was later disproved, but not before some strikingly beautiful curvilinear glasshouses had been built, some of which remain. MacKenzie's idea was taken up and developed by John Claudius Louden, the great Scots writer on garden design and architecture. The curved shapes could best be formed using slim wrought iron glazing bars and, with the help of the ironworks of W & D Bailey of Holborn, he had a prototype range erected in his large Bayswater garden. By the 1830s many such glasshouses were being supplied to discerning plantsmen.

Turner

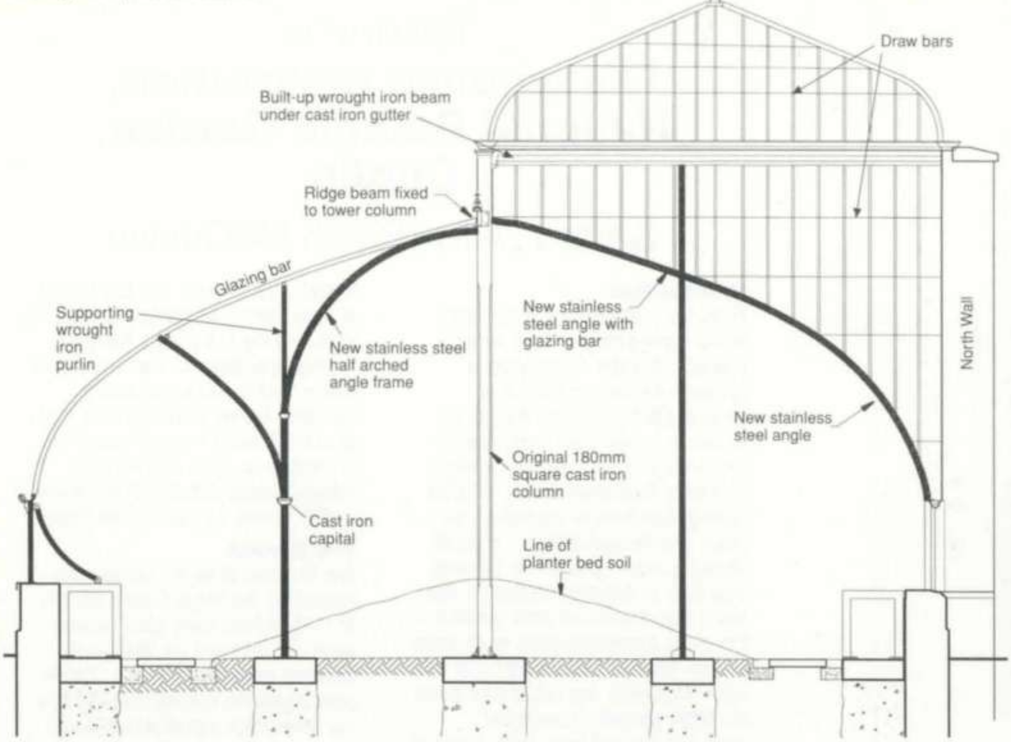
Richard Turner, from a long line of Dublin ironmongers, was familiar with the work of Louden and the Baileys. In 1833 he set up his own Hammersmith Ironworks near Dublin and eventually became the greatest ironmaster of his day. His best-known work is undoubtedly the Palm House at Kew but he also built the Belfast Palm House, the Lily House at Kew, the Wintergarden at Regents Park and the Curvilinear Range at the National Botanic Garden, Dublin. Also noted for his engineering designs, Turner's trussed arch roof at Lime Street, Liverpool, was the greatest then built, and he was deeply disappointed at coming second to Paxton for the Crystal Palace.

The Garden

The National Botanic Garden was started by the Royal Dublin Society in 1795. All the early glasshouses were of wood and by 1842 were deemed unworthy of repair. Turner persuaded the Society that the new curvilinear iron construction would be superior and the first phase, ironically not by Turner but the little-known William Clancey, was completed in 1844 - the 30m long East Wing. Turner later added the East and West Passages and the West Wing (1846) and completed the range with the Central House, intended as a Palm House, in 1848. The entire range, as was customary, was south-facing with a solid north wall and was formally opened by Queen Victoria in 1849. The East and West Wings proved too narrow, and in 1869 Turner doubled their width by inserting arched wrought iron angles springing from the slim wrought-iron columns and thus relieving the old north walls (subsequently removed) of their supporting roles. He also provided two glazed towers to join the new construction to the earlier, and new iron doors at the east and west ends. *Continued* ▶

1. Restored spherical glazing in wings, with 2. (inset) Showing appearance before restoration.

3. Wing/tower junction restored.



4. Pilasters, gutters and sashes in wings.

Structural survey

In 1984 Ove Arup & Partners Ireland surveyed the building to ascertain how it had been assembled and to assess deterioration. The wings and passages, though at first sight of similar construction, were found to differ in a myriad of detail.

Cast iron pilasters at 1.2m centres are socketed into the plinth wall with cast iron gutters spanning on top. Curved wrought iron glazing bars stretch from the gutters to the apex, supported en route on a wrought iron purlin that spans over a row of slim 38mm diameter wrought iron bar-columns. In the wings these bar-columns are 'boxed' by the angles, arched at high level as provided in the width-doubling extension. There are pivoting wrought iron sashes between the pilasters and sliding sashes on the roofs. The two towers are about 5.3m square, projecting above the adjoining wings and passages.

Each vaulted roof is supported on a cast iron gutter sitting on the north wall or on wrought iron beams spanning onto two 180mm square cast iron columns; the spandrels are glazed in a framework of wrought iron bars.

The centre house is about 18.4m x 9.7m, and at 10.3m the tallest. The glazed walls incorporate glazed 550mm wide double-pilasters, of 50mm x 50mm wrought iron bars forged into a unit.

On top are cast iron gutters from which the quadrant glazing bars curve to the central clerestory. This and the lantern are supported on two rows of full-height box-columns, each of two 100mm x 100mm wrought iron angles with cast iron ribs bolted on. Cast iron lantern gutters span over the box-columns and carry the glazed lantern; a series of wrought iron tie-bars and arched bars provide stability.

The building clearly required a complete overhaul. After nearly 150 years corrosion was rife: the ridge in each wing had pulled apart, none of the opening sashes worked, many grey iron castings had cracked, and a multitude of ad hoc repairs in mild steel were showing distress.

In 1990 Ove Arup & Partners Ireland was commissioned by the Office of Public Works for a complete refurbishment.

Restoration

A plan was produced that included new buildings to the north and a restoration of the curvilinear glasshouse. For the glazing bars various options were possible.

Wrought iron was no longer made and the alternatives of using extruded stainless steel or aluminum sections were considered. The client, though, expressed a wish for a 'faithful restoration' with materials as originally used, except where change was necessary.

Providence took a hand when it was discovered that a Bristol firm could forge lengths of glazing bar of the required section, using quality scrap salvaged from anchor chains and the like.

Also, a quantity of old wrought iron glazing bars became available from the Palm House at Kew, where stainless steel had been substituted.

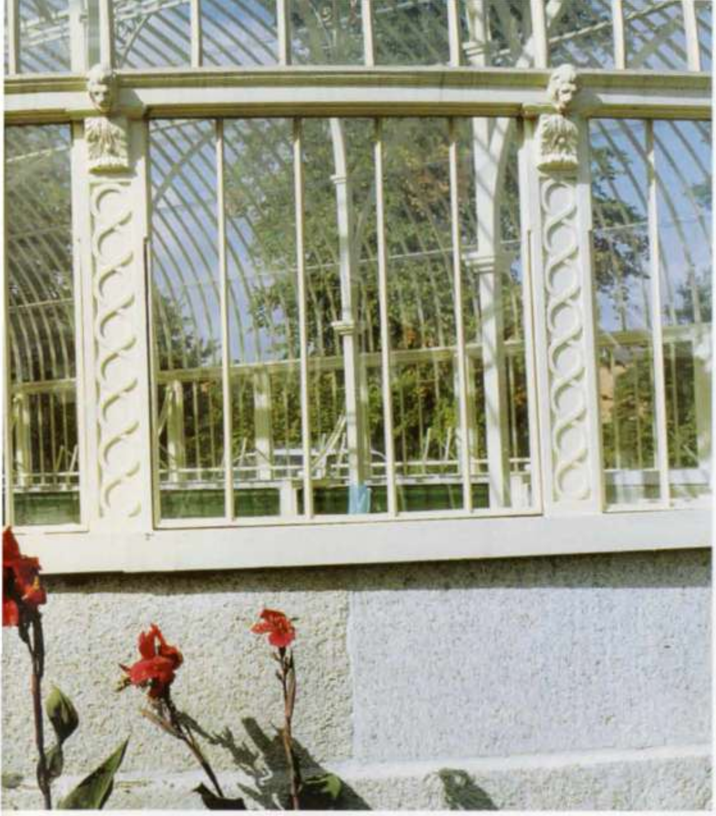
The forging process was thus to produce the various glazing bars and round bars required, and the Kew bars, originally provided by Turner, were brought home to rejoin their fellows.

Preliminary testing of the wrought and cast irons showed them to be of reasonable quality, as was a sample of newly forged glazing bar; butt welding of the glazing bars also proved to be satisfactory. Computer analysis of each structure revealed areas where, *pace* 150 years of service, robustness could be improved, and a number of design interventions were therefore made:

- A shallow stainless steel ridge beam was introduced in each wing with intermediate column supports which also provided vertical service ducts.
- The width-doubling arched angles in the wings were replaced in stainless steel, as were the boxed lengths of the bar-columns; this to prevent a repeat of earlier corrosion.
- New curved ductile iron braces were provided at every second pilaster in wings and passages.
- All the sliding roof-sashes and the large pivoting sashes in the Central House were renewed in stainless steel.
- A new tie was required in the Central House lantern roof to resist spreading.
- The ad hoc accretions of welded mild steel straps, angles, and braces were removed.

Contract

The refurbishment contract commenced in December 1992 and lasted about two years. An accurate survey of the existing construction was followed by phased dismantling of all ironwork; a comprehensive tagging system was used and each element of cast and wrought iron was inspected and scheduled for repair or replacement - there were over 8km of glazing bars alone. An initial grit blast facilitated the inspections. All faulty cast iron was recast, using ductile iron in areas of high stress. The wrought iron glazing bars required new trimmer bars top and bottom and short lengths of corroded bar cut out and new-forged bar welded on, mainly at each end; each bar was then checked and adjusted for curvature against a fixed template.



Cages of glazing bars were then assembled in the workshop and checked for fit before painting. To safeguard against bimetallic corrosion, isolating bushes were provided where the stainless steel assembly bolts would pass through the wrought iron; all contact surfaces would be painted and fully bedded in mastic.

All painting except the final coat was done in a controlled environment in the paint shop - a total of six coats on the wrought iron and seven on the cast iron - and a proprietary mortar was therefore substituted for molten lead in the plinth sockets. Spectroscopic analysis showed Turner's original paint to be off-white with a hint of yellow and this was recreated in the polyurethane finishing coats.

The contract also included ancillary buildings on the north side for plantroom, offices, and exhibition area; also the rebuilding, now faced with granite, of the north plinth walls. The services comprise fully automatic temperature and humidity controls and motorised sash operation, all to provide a tropical climate in the West Wing, temperate in the Central House, and mediterranean in the East Wing. Service runs were specially designed to be as unobtrusive as possible and shading, if required, will be by internal fabric suspended from the roof. The total cost was about £3.5M and the building was formally opened in September 1995 to mark the 200th anniversary of the Gardens.

Credits

Client/architect/service engineers:
The Office of Public Works

Structural engineers:
Ove Arup & Partners Gerard Duffy, Macartan Haverty, Ralph McGuckin

Ironwork sub-consultant:
Posford Duvivier

Quantity surveyors:
D L Martin & Partners

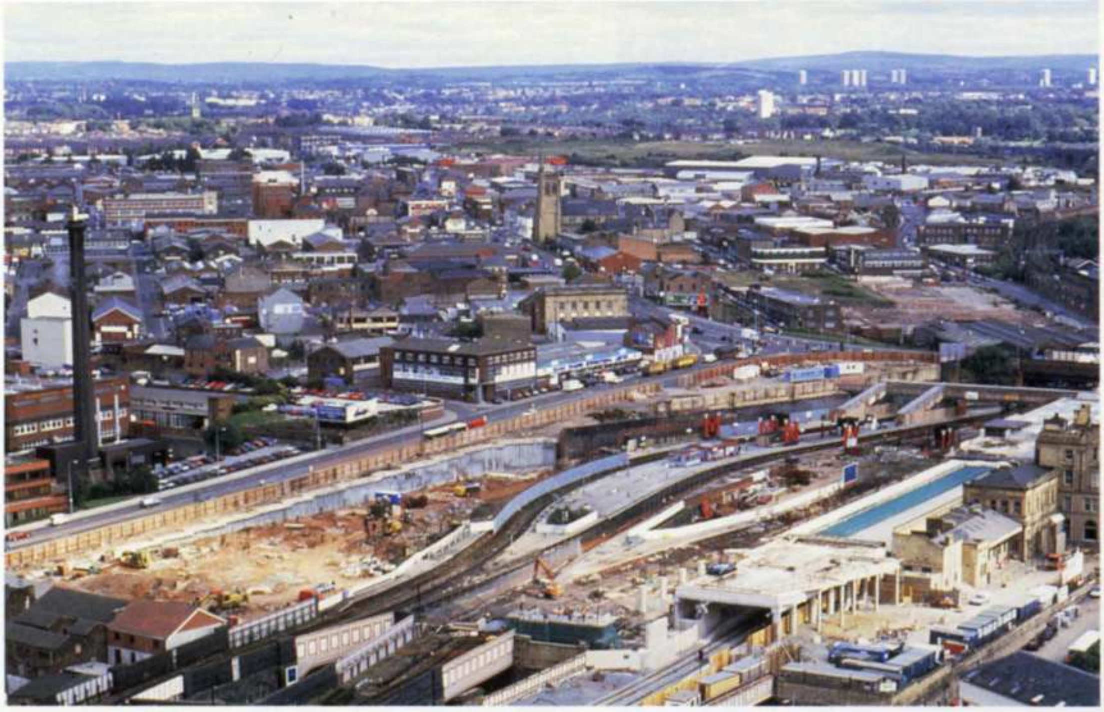
Main contractor:
John Paul Construction Ltd

Ironwork sub-contractor:
Shepley Engineering Ltd

Forged ironwork:
Dorothea Restorations Ltd

Illustrations:
1, 2, 4, 5: Mary Croke Photography
3: Ove Arup & Partners Ireland

5. Below: The restored range.



1. Right:
& 2. Below: Site before development.

The Nynex Arena, Manchester

Steve Burrows
Paul Kay
Darren Paine
John Waite

3. Below: Site after development.

Introduction

Manchester's Olympic 2000 bid, and a strong desire to regenerate the city's north-eastern sector, made the Arena a reality. Following Manchester's success as UK Olympic bid representative in 1991, Government promised in March 1992 to part-fund and thereby guarantee construction of facilities, on the basis that the three major sporting facilities would be constructed on inner city regeneration sites. In June 1992 Vector Investments won the competition to develop a 20 000-seat arena over the Victoria Station rail interchange. The race to show that Manchester would have world-class facilities at its disposal before the year 2000 began.

The challenge

The site was the 14ha of Manchester's Victoria Station, and the scheme was to bring forward redevelopment of the Station itself, and release a large tract of land for the new facility (Figs.2 & 3):

- Arena (occupancy licensed at 20 500)
- Multi-storey car park (1000 spaces)
- 'City Room' (retail accommodation)
- Multiplex cinema shell (leisure)
- 'Arena Point' (office accommodation).

The station had to operate throughout construction, which led to a phased building programme that in turn affected the design, particularly where structure was adjacent to or over railway lines. Programme and cost were high priorities. Demolition was scheduled to start late December 1992, with completion by 30 June 1995. The first 12 months were mainly concerned with the station redevelopment, although small pockets of the site were released for Arena construction. Based on November 1992 scheme stage information, Bovis boldly gave a guaranteed maximum price (GMP); this had a continuing impact on the design, having strict cost targets for each part of the project.

4. Elevation of completed Nynex Arena (left) adjoining Arena Point office block.

Site history and geology

The site was originally at the confluence of the Rivers Irk and Irwell, and development there was traced back to 1793 when it was occupied by a workhouse. In 1844 the Lancashire and Yorkshire Railway began operations from the site, and railway activities continued expanding until 1900, since when the site had remained reasonably static. The Rivers' influence on the geology is marked, with rock contours dipping into each of their valleys. The Ardwick fault also crosses the site. Boulder clay overlies Bunter Sandstone bedrock, the bearing strata for the foundations - a typically Mancunian progression. Geology more than soil mechanics influenced foundation choice, which varied from piles through pad foundations to ground-bearing slab, depending upon the distance from formation level to rockhead.

Arena structure

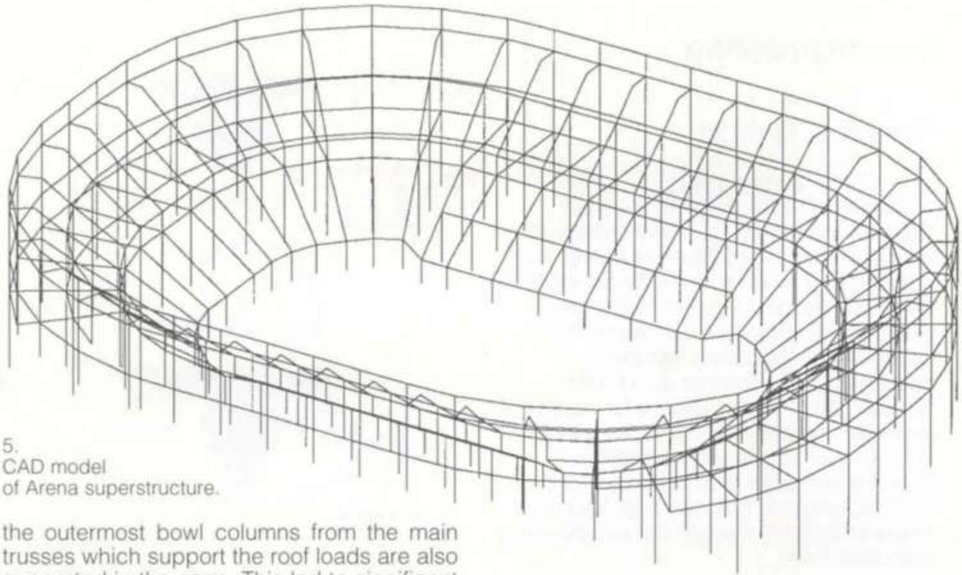
Analysis

It was decided at an early stage to create a three-dimensional CAD model (Fig.5) for the entire superstructure; this could show the expected displacements through various construction stages, as well as determine forces developing in the ring beam. The latter was to prove most critical when it was intended to start erecting the roof trusses prior to completion of the frame. One-third of the superstructure would be incomplete when the first truss was placed, and the model showed the net effect on the incomplete frames. There was a slight load reversal in the end frames, but overall deflections were within expected limits.

Structure

The in situ reinforced concrete structure comprised 44 frames on a radial grid, stabilised out of plane by continuous in situ beams, which form the bowl, supporting upper and lower walkways. The concourse and upper walkway are in precast, prestressed, hollow core planks, whilst the terracing is of precast normally reinforced concrete.

The Arena is partially built over the realigned Victoria Station platforms on a transfer structure which also forms the concrete slab to the Arena at concourse level. To meet BR requirements for the station's operation, and allow for future electrification, the maximum allowable structural depth was 1m for a clear span of 17m. An initial scheme of plate girders and double-Ts was selected for ease of construction and programme, but subsequently replaced on cost grounds by a voided reinforced concrete slab. The transfer structure supports one column at mid-span, typically. However, at the ends of the bowl, the outermost bowl columns from the main trusses which support the roof loads are also supported in the span. This led to significant pre-cambering to control deflections of the transfer structure.



5.
CAD model
of Arena superstructure.

Construction

Modern building projects call for faster and shorter construction periods. For speed, the superstructure contractor chose an American steel shuttering system, the shutters forming the raking beams and the stepped profile as complete units including all necessary walkway supports and fixings. The reinforcement cage is lowered into the shutter on the ground and then the whole assembly lifted into place and fixed to the columns. After concreting, the shutter splits and is lowered to the ground.

This system led to some rationalisation of the design of the frames, each being detailed as a complete elevation allowing easy co-ordination between beams and columns. The shuttering meant that starter bars could not be accommodated if they were out of the plane of the frame, so a system of sleeves to allow bars for the ring beams to be fixed later was introduced.

Terracing

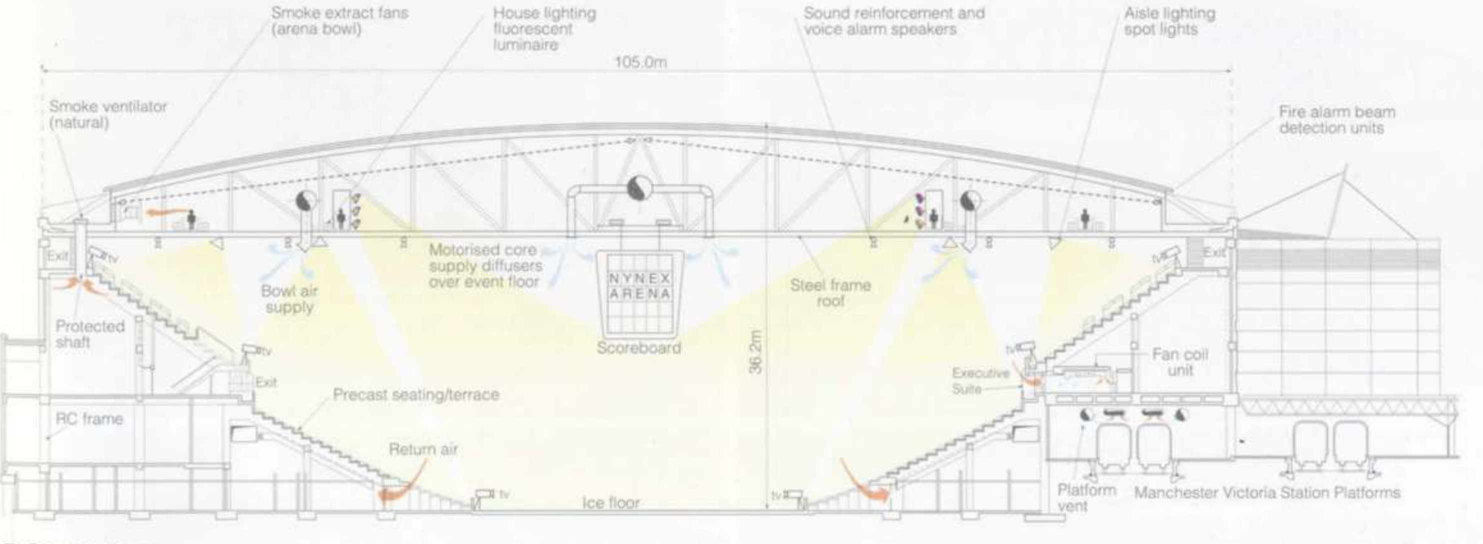
All terracing was precast. The lower level has a varying step depth for sight lines, which resulted in single L-shaped units; the upper has uniform rise and could be prefabricated into double units. The typical unit length is 7.5m, but varies radially from 4m-10m. Fixing was by a series of dowels and pockets cast into the frame and unit which were then grouted to give a firm fit. The joints between each unit were fire-stopped with an epoxy to match the finished concrete.

6. Arena concrete frame under construction.

Arena roof

The roof, large both in area and in span, carries superimposed loads ranging from event equipment to more traditional elements such as snow. An easily buildable and flexible solution was a truss, spanning 105m across the event floor (Fig.7), with orthogonal trusses at each end to form a curved upper surface.

In a roof design of such sheer scale, all effects are magnified beyond structural engineers' traditional figures. For example, the thermal effects on a roof covering 1.52ha are of great significance.

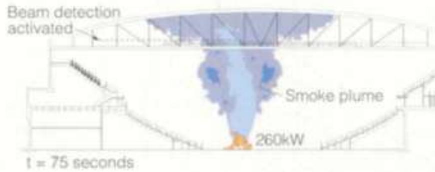


7. Cross-section.

Fire engineering

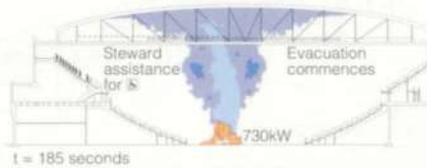
Chris Barber
Peter Bressington

Classed as a 'place of assembly', the Arena is beyond the scope of current building regulations in terms of fire. A comprehensive solution encompassing the whole development, including the Arena, had to be developed. With a licensed occupancy of over 20 000 people, their safe and timely egress dominated the fire strategy. Initial discussions with the City's Building Control Officers centred around *BS5588: Part 6* 'Code of practice for places of assembly'. However, it became clear that the solution could not follow this standard in providing evacuation in 2.5 minutes. Rather, it lay in exploiting the building's huge volume for smoke control and management, and extending evacuation time.



A. Fire detected.

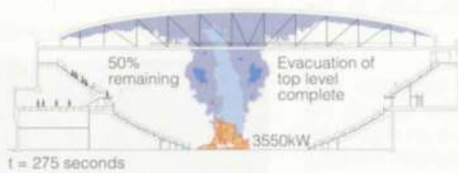
B. Start of evacuation.

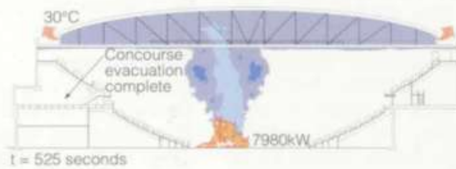


A timed egress analysis at full occupancy was undertaken, together with the rate of smoke production from a growing fire. Both were considered with the rate that smoke would stack down from the roof, and the provision of high level smoke extract. Fire growth rates and size as agreed with Building Control were based on pop concerts, where the stage and the amount of combustible material was considered the greatest risk.

The analysis took account of the time taken for fire detection and a period of mobilisation of people to start evacuation (Figs.A-D). No mechanical extract was assumed until 400 seconds after the fire began, when the fans would be fully within the descending smoke layer. Overall evacuation time was calculated at 6.5 minutes for people to leave the Arena bowl. From timings of normal evacuation at the end of major shows, this has been shown to be slightly conservative.

C.
Top level emptied.





D.
Concourse clear of people.

In this case the solution was to have only one point on the roof - the centre point - that remains static. At the four compass points, pairs of sliding guided bearings maintain overall stability, with all other points bearing free. Thermal loads are thus not transmitted to the frame and lateral displacements are contained to the ring beam level.

The scoreboard - an 8m cube - also presented a challenge, primarily due to its location in the centre of the roof and the requirement for it to be raised and lowered to suit particular events and for maintenance. As this heavy load also coincides with the centre stage rigging load and the maximum span, the pair of centreline trusses became the design case.

Erection method was also a design fundamental: pairs of half trusses were lifted at mid-span on military trestles, which were removed after connection. This attracted considerable public interest in an event expertly performed by the erectors.

Multi-storey car park

The 1000-space car park was designed to extend vertically as part of stage 2 of the development, and is also intended to house within its envelope gymnastics warm-up facilities for Olympic and/or Commonwealth Games. The parking floors themselves are unusual in the use of post-tensioned reinforced concrete to create a long-span structure with minimal intrusion of beams. This was to enable good consistent lighting levels across the spaces, and a minimum storey height to ease ramp access between the split levels. Both criteria, apparently conflicting but intended to give a feeling of security to the user, were achieved. The multi-screen cinema was created by omitting car decks to form an open box within the car park envelope. Some use of transfer beams to maintain this clear space was needed, but the flexibility of space that results has significant attractions to potential operators.

8.
Roof truss lift.

9. Below:
Concrete frame almost complete with half of roof steelwork erected.

'City Room'

The box office entrance to the Arena is at the mid-point of the complex above the station, which necessitated access up to this level from the station concourse, the multi-storey car park, station platforms, and the public highway. The area into which each of these leads - the City Square - abuts a voluminous space known as the City Room, which in Phase 2 will be extended into a major retail development.

This is built over the four new platforms created in the Victoria Station redevelopment, and is designed to accommodate a future mezzanine level adjacent to the City Square.

The deck is of similar construction to the main Arena transfer deck using voided slabs spanning between platforms. Above this level a steel frame with pinned tubular trusses spans 32m over the space, incorporating a feature glass roof as a focal point. The key feature of the City Room is its unifying ability in its location above an operational railway station. The City Square, whilst separate from the Arena, multiplex and car park, forms one of the main thoroughfare means of escape from the complex, and is fully protected with natural smoke ventilation, sprinklers to retail units, full fire detection, and a multi-functional PA/VA system. It is naturally ventilated and includes a track lighting system to allow flexible use of the space for small exhibitions, advertising and the like.

It is intended that Phase 2 of the development will extend the City Room into a major retail development, and the design respects this intent.

Arena Point

Arena Point is a 2500m2 speculative office development situated at the Hunts Bank entrance to the Arena above the west end of the redeveloped station. All four through lines run directly under the building, which was only designed after the transfer deck was completed. It has a traditional lightweight structure of composite metal deck on a steel frame, with lightweight cladding to each elevation. Lightweight structures are particularly sensitive to vibration, and so acoustic isolation and the natural frequency of the building were carefully considered to ensure the comfort of the users.

The development was designed as shell-and-core, with the fit-out of the offices to be by subsequent tenants. Central mains services were provided for mechanical, electrical and public health systems, including incoming services, boilers, chillers, ventilation plant, mains power, and fire alarms. All landlord's areas were fully fitted out.

Mechanical services

The Arena being a multi-purpose event facility seating over 20 000 people, its services have to take into account a wide variety of environmental conditions. The various activities and occupancy levels require a flexible services design that can be easily operated to suit the variable needs.

Plantrooms

The Arena is such a vast building that plant space is not an issue, but the position of that space was subject to some hard negotiations. Typically, such large multi-purpose facilities have four main plantrooms at high level in each corner. With such a restricted site and cost constraints, good use of 'cheap' space was vital. The main air-handling plant is located under the concourse in the huge void below the lower tier seating. A height of over 5.5m was available, ideal to house the large plant to be installed. Total central plantroom space was in the region of 2 700m² and in three main locations:

- North mezzanine level: Arena bowl, changing rooms, performer and star changing and press accommodation ventilation systems. Water storage and sprinkler tank.
- West mezzanine level: HV & LV substation. Emergency generator. Building operations and main kitchen ventilation systems.
- East upper walkway level and roof: Chillers, ice floor heat rejection plant, offices ventilation, boilers, pumps, domestic hot water supply, storage area ventilation.

10. Arena Point office building.

Acoustics

Iain Clarke
Neill Woodger

Site-wide Issues

The location in terms of noise and vibration isolation was far from ideal. Of the four realigned rail lines, two were actually under the southern concourse and higher tier seating, giving rise to concern over train-induced noise and vibration. Also, Chetham's School, Parkers Hotel, and Boddingtons Brewery nearby were sensitive to noise break-out. Two surveys were carried out, one to establish noise and vibration from rail activity, and the second - a targeted environmental noise survey - to determine the existing day, evening and night noise levels. The results led to the following work:

- under-sleeper rail isolation beneath all tracks within a 20m radius of the stadium (Fig.E)
- design of the structure to limit dynamic structural amplification of structure-borne vibration
- use of reinforced concrete (rather than steel) as it transmits less sound
- acoustic absorption of the station 'box' under the southern concourse
- Establishment with the Environmental Health Officer appropriate criteria for limiting the noise leaving the Arena
- Specification of the Arena roof and wall elements to ensure that adequate sound trans mission and acoustic absorption was achieved.
- Detailed analysis of noise emission from the ventilation systems.

Arena Bowl

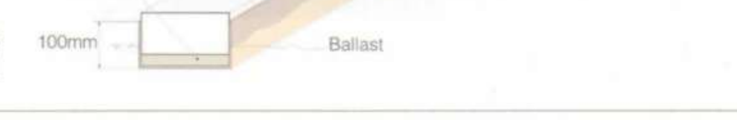
Factors determining optimum reverberation characteristics for an arena include intelligibility of the voice alarm system, stability of acoustic between full and part-full events, and the 'liveness' of the space to reinforce crowd cheering without allowing excessive noise build-up.

Acoustically absorptive seating was adopted for reasonably high absorption when the Arena is empty. The roof deck incorporated an inner perforated sheet exposing mineral wool for absorption. In addition, woodwool slabs were attached to the top deck rear walls to prevent unwanted late reflections during music events.

The public address and voice alarm (PA/VA) system integrates high quality sound reinforcement, voice alarm and general public address.

For speech to be intelligible it was concluded that a maximum of 2.75 seconds reverberation time @ 2kHz was required, utilising a fully distributed system of high powered cabinet speakers served from central rack rooms.

The system, one of the largest of its kind in Europe, was fully tested during commissioning and achieved all design expectations.



E. Schematic of undersleeper pad.

Heating, ventilation, and cooling

The Arena bowl is heated and comfort-cooled utilising an all-air system. Various methods of air distribution were investigated, taking into account the location of the central air-handling plant, main riser positions, main duct entry positions, and optimum distribution into the space. Computational fluid dynamics (CFD) were used to analyse air movement and comfort levels.

Displacement ventilation below the seats is the preferred method for large auditoria but could not be accommodated in this case, so an overhead ventilation system was adopted utilising high volume swirl diffusers providing a highly induced air distribution throughout the space (Fig.7). The total system air volume for the Arena bowl is 170m³/s.

Noise levels within the space were targeted at NR40, which may appear high but was intentionally so to mask the worst of rail traffic passing underneath and the fact that the main events are sports or pop concerts and not classical music.

Main locker and changing rooms are fed by individual ducted air-handling plant without cooling. All offices, executive suites, performers and star changing rooms are comfort-cooled utilising fan coil units individually controlled via the building management system (BMS).

Low pressure hot water (LPHW) heating is supplied by four 1500kW gas-fired boilers with a primary circuit temperature of 85°C flow, 65°C return. Chilled water is split into two main systems. The first has two 1000kW packaged air-cooled chillers serving the main Arena bowl, whilst the second employs a single 200kW package chiller to serve three zones (administration, executive suites, and performers). The chilled water circuit temperature is 6°C flow, 12°C return.

Ice floor

A permanent international ice hockey-sized (60m x 30m) ice floor is installed, comprising central chilling equipment, external wet-cooled condensers, pumps, interconnected pipework and fittings, ice floor cooling headers, substrata heating system and system controls. An ethylene glycol coolant system was selected for this installation to avoid the concrete protection that is necessary with a brine system.

A curved header trench directly adjacent to one end of the ice floor is provided to avoid cold areas of floor and subsequent surface condensation problems. A link trench between the refrigeration plantroom and ice floor connects the header services with the main chiller plant. The design provides a minimum ice floor temperature of -10°C with a corresponding external temperature of 25°C db, 19°C wb.

Electrical services

Supply and distribution

Two independent 6600V supplies, with translay relay protection to provide a high degree of security, power the Arena. Each is linked in the form of a ring between three strategically located sub-stations, each housing vacuum-operated ring unit switches and two 1.0MVA Securamid dry type transformers. All operator power supplies are distributed from each sub-station to vertical core risers to all floor levels.

Concert stage power is provided by specially designed bulk stage panels at each end of the Arena floor and on the catwalk above to provide maximum flexibility.

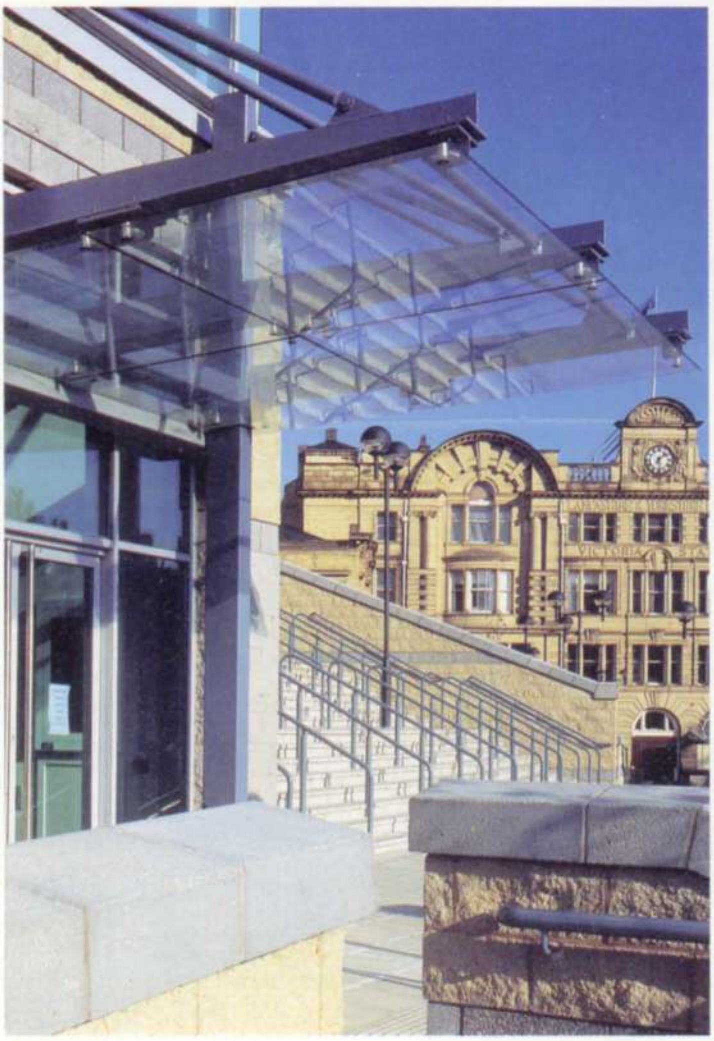
Dedicated power supplies and cable carrying systems are also provided for TV facilities throughout the Arena bowl. A dedicated power supply of 100kW is also installed to the largest four-sided central electronic scoreboard in the world.

Lighting

The Arena bowl lighting is designed to meet fully with the Olympic International and TV standards, in particular those relating to CIE 67, 83 in conjunction with the CIBSE Sports Lighting Guide and Sports Council requirements. Close liaison with TV companies was carried out during the design process to ensure that the lighting was suitable for televising the many varied events. The main event lighting comprises 120 metal halide floodlights, each rated at 1800W, mounted on the overhead catwalk.

These compact lights provide a good colour rendering index of Ra 92 and are ideal for use with daylight (5500K) balanced film stock, eliminating the need for colour correcting

11. Right:
Arena interior during an ice hockey match.



12. Left:
Arena entrance, with Victoria Station in background.

13. Left:
City Room to Victoria Station entrance doors.

filters. The sports lighting was designed to cater for volleyball, basketball, ice hockey, ice shows, gymnastics and boxing events with average lighting levels set from 500-2000 lux, depending on whether the event is county, national or international standard.

The Arena house lighting consists of linear fluorescent luminaires containing high frequency regulating gear. This allows controlled dimming of the lighting output in all public seating areas to add to the mood of anticipation and excitement before and after concerts. All lighting luminaires have been designed with rear access to allow for easy lamp replacement from the catwalk.

Emergency lighting to all public areas is provided to a minimum level of 2 lux using four 240V static inverter battery units. In addition, safety lighting to a level of 1 lux is provided to the aisles during all periods when the bowl is occupied. Dimmable tungsten halogen spotlights are used, each with a unique manufactured gobo and slot for illuminating the exact shape of the aisle without spillage into the seated areas.

All Arena bowl lighting is operated from a microprocessor-based management control system. This control system provides easy, user-friendly operation from supervisor desktop PC stations with graphical view of lighting status, lamp failure and run times.

Simple push-button and selection routines allow the operator to choose the appropriate light programme for each event or re-configure different lighting patterns as required. Additional specialist Arena bowl lighting includes follow spotlights for concerts, and strobe lights for still photography.

Communications

TV cabling is provided in all suites, scoreboard studio, administration, and operations rooms, with aerial and satellite dishes erected at roof level, whilst the communication systems include a voice and data service distributed using fibre optic cabling throughout the Arena. Strategically-located CCTV cameras are positioned at high level within the Arena bowl, main concourse and public entrances linked to the security and management operations room for crowd control during events.

Conclusion

Work started on site during the Christmas holiday of 1992 and was completed on 30 June 1995, precisely on programme and within budget. Given that the Arena is such a complex facility, built on a tight city centre site under difficult operational circumstances, the success of the project is a credit to all concerned.

Support continues to grow for the resident ice hockey and basketball teams, and already major concerts have been held with Wet Wet Wet, Blur, Oasis, Pavarotti, Rod Stewart and 10 nights of Take That - all hugely successful.

Manchester looks forward to seeing the Arena in full use during its hosting of the 2002 Commonwealth Games.

Reference

(1) BICKERTON, G *et al.* Manchester Victoria Station redevelopment. *The Arup Journal*, *30*(3), pp.12-14, 3/1995.

Credits

Client:
Vector Investments Ltd
Executive architect:
Austin-Smith: Lord
Arena architect:
DLA Ellerbe Becket
Quantity surveyor:
Davis Langdon Everest
Consulting engineers:
Ove Arup & Partners Geoff Bickerton, Peter Budd, Steve Burrows, Gerry Eccles, Mark Elsegood, Richard Hattan, Ian Humphries, Charles MacDonald, Andy Marsland, Darren Paine, Roy White, Colin Wood (structural)
Jane Collins, Colin Curtis (geotechnical)
Paul Holder, Austin Smith (civil)
Bob Baker, Dennis Harrison, Paul Kay, Ian Stuart, Andrew Woodhouse (mechanical)
Graham Britton, Grant MacDonald, Stuart Redgard, Pat Thorpe, John Waite (electrical)
Mike Buckingham (public health)
Chris Barber, Peter Bressington (fire engineering)
Iain Clarke, Neill Woodger (acoustics)
Andrew Allsop (wind engineering)
Management contractor:
Bovis Construction Northern Ltd
Illustrations:
1, 8, 14: Len Grant
2, 3, 5: Trevor Slydel
4, 10, 11-13: Ian Lawson
6, 9: Bovis Construction Northern Ltd
7, A-E: Jonathon Carver/Peter Speleers

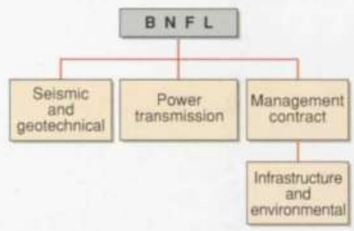
14.
The completed Arena.

Siting nuclear generation facilities

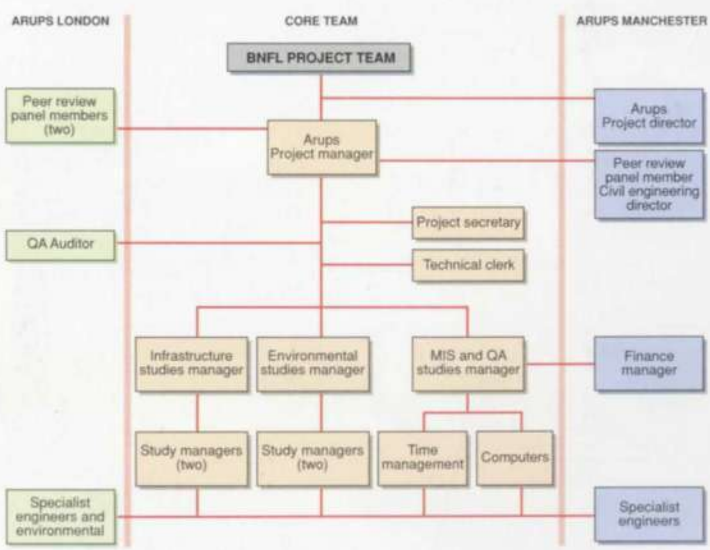
Paul Murphy Keith Rudd Fraser Smith Robert Warren

1. The existing Chapelcross power station.

2. Main elements of Phase 2. ▶



▼ 3. Arup project team.



Introduction

In December 1988, the British Nuclear Fuels plc (BNFL) Board approved the proposal for a feasibility study into building new pressurised water reactors (PWR) at Chapelcross, near Annan in Dumfries and Galloway, and at Sellafield in Cumbria. Phase 1 of the study, completed in September 1990, concluded that both sites were suitable for the location of at least one major reactor up to 1500MW, and that current PWR technology could provide electricity at costs comparable with conventional coal-fired power stations. Potentially, there could be two reactors at each power station with an estimated development cost of £6bn.

In January 1991 BNFL announced its decision to extend the study into a second phase, in which technical and environmental factors would be examined in more detail. Ove Arup & Partners were appointed as management consultants for this Siting Study, following the submission of a detailed technical and financial proposal. This article describes the management contract at Chapelcross and Sellafield which the firm undertook during the three years of Phase 2, a project which involved 46 specialist firms as technical contractors. Altogether, the project has five phases.

In May 1994, the Government announced a review of the UK nuclear industry. The timing of the review, and the period which BNFL will require to assess its outcome, created an uncertainty about the start of Phase 3 and the subsequent detailed design and construction phases. The resulting discontinuity had a direct effect on the nature of the Environmental Statement that was part of the management consultant's contract.

The Phase 2 Siting Studies

Purpose

BNFL intended to complete the feasibility study during Phase 2 in order to:

- confirm the suitability of the sites for power station development
- provide the basis for a full Environmental Statement for each site to accompany future consent applications
- provide preliminary infrastructure design and input to selection of the nuclear reactor and a Class 'A' cost estimate (i.e. -10% to +15%)
- support the Planning Consent and Site Licence application and subsequent Public Inquiry.

Organisation

The three main elements of the Phase 2 Siting Studies were the seismic and geotechnical study, the power transmission study, and the infrastructure and environment studies, all directly co-ordinated by BNFL (Fig.2).

Because of the large number of infrastructure and environmental studies, and the wide-ranging disciplines they required, BNFL decided during Phase 1 to bring them together to be managed by a management consultant responsible for setting up and implementing the studies, but reporting regularly to BNFL. Arups were also separately appointed for the geotechnical and tunnel studies, described in a previous issue.[1,2]

Project team

Arups' multi-disciplinary core team (Fig.3) mirrored BNFL's own multi-disciplinary management structure, as stated in the tender documents, which envisaged the management consultant setting up his team within BNFL's organisation at Risley near

Warrington. After discussion, however, it was agreed that the Arup team should be located at the firm's Manchester office. It was generally 11-strong, but was regularly and extensively supported by specialists of differing environmental and engineering disciplines from Manchester and other Arup offices. BNFL's own siting studies project team of three had to be provided with a dedicated office in the same building, and this encouraged close collaboration between the two organisations - one of the key features in achieving a successful outcome to a long and complex contract.

The team was established as a self-contained group separate from the main Manchester office but just across a corridor. This was doubly beneficial in that the team built up a sense of project unity by being set up from scratch, but also retained a feeling of being part of the Arup Manchester office - something that would have been virtually impossible to maintain had it been at Risley.

Contract management

Pre-qualification, assessment and award

A comprehensive pre-qualification exercise was established to ascertain the extent of interest and suitability of consultants to bid for their studies. This took the form of a questionnaire sent to suitable companies, requesting details of their experience of similar work and their choice of which studies they would prioritise should they only be selected to bid for a maximum of two or three.

Shortlists of tenderers were drawn up and approved by BNFL, usually consisting of three or four firms if the study was not likely to exceed four months and £100 000, and up to eight for those of much higher value, longer periods, and greater complexity. Their tenders were assessed by Arups, withholding the financial element from those undertaking the technical assessment until a shortlist of usually two had been arrived at entirely on technical merit. Meetings with finally shortlisted tenderers were conducted by BNFL, with commercial negotiations towards contract agreement carried out between their Purchasing Group and the preferred firms.

Contract documentation

Despite the many studies of widely differing scope and disciplines, it was possible to create uniformity in the layout of tender documents, weekly and monthly reports, and cost reporting systems.

This was essential for effective management of the studies, and prompt understanding of the considerable amount of information that had to circulate between the technical contractors, and from them to the management consultant and BNFL.

Management of change

The studies were let on a lump sum basis. However, because of the changing scope of some of them and the need to be flexible as early results became available and conclusions and decisions on the choice of options were taken, it was necessary to establish a system for identifying change and assessing its effect before issuing a formal variation. This became known as the Study Change Notice procedure. The effect on project cost and timetable was assessed by Arups for each change, and reported to the BNFL project team. If approved for implementation, BNFL Purchasing issued the formal change order. The total effect of all Study Change Notices was summarised in the Monthly Cost and Progress Reports to BNFL.

Performance, milestones and retentions

A financial monitoring arrangement was established, whereby output from and progress of studies were measured against a series of key dates or milestones, against which there was a holding of retentions. As management consultant, the firm was also subject to this cost and performance control system. Milestones were created at approximately three or four-monthly intervals, when significant deliverables or achievements were due.

Release of the accumulated previous retentions was made, provided the milestones had been achieved, otherwise withholding continued until the corrective action plan was achieved.

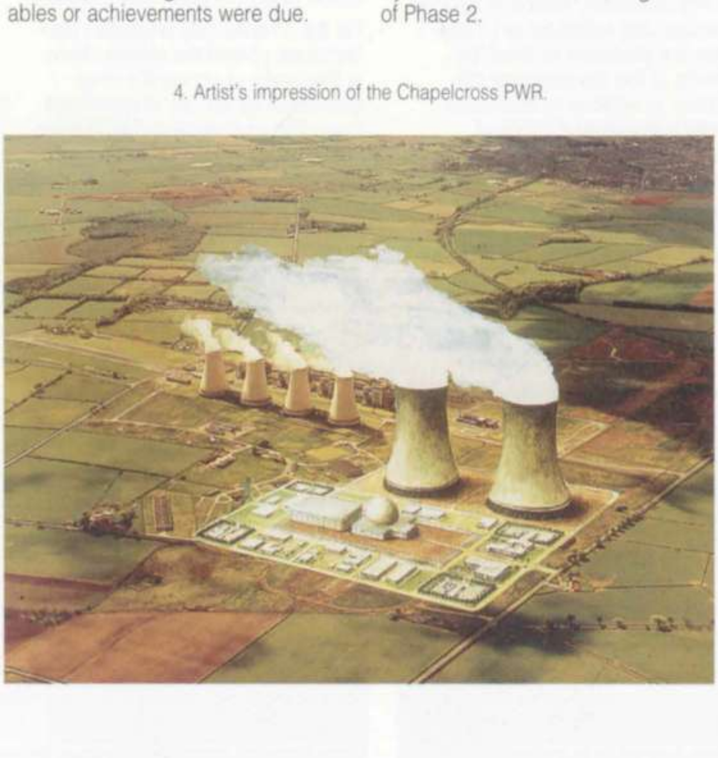
Management Information Systems

The challenges

Interaction of the Phase 2 studies was a complex management problem, for which BNFL were responsible. Together they comprised commercial, reactor, and safety case studies, as well as the Siting Studies. Within the latter BNFL were also responsible for overall management of the transmission, geotechnical, and seismic studies. The infrastructure and environmental studies were managed by Arups. Against this, however, the final consequence of Phase 2 was the Consultative Environmental Statement, for which Arups was the author. This required input not only from the infrastructure and environmental studies under the firm's control, but also from all the other studies directly managed by BNFL.

The fact that there were no less than 46 separate infrastructure and environmental studies indicates the scale of the management task, with many interactions between the various technical contractors carrying out the studies and also interested third parties such as consultees. The Management Information Systems therefore had to be capable of supporting the management team in the production of study scopes, managing studies and, ultimately, the Consultative Environmental Statement, as well as being usable by BNFL in the overall management of Phase 2.

4. Artist's impression of the Chapelcross PWR.



The solutions

Careful consideration was given to what information would be required and by whom, how it would be used, how to avoid duplication, use of electronic transfer, and how it could be utilised after Phase 2, at any future Public Inquiry. The *modus operandi* developed around computerised information storage and retrieval systems like CD-ROM, so that references to any particular subject (e.g. natterjack toads), could be quickly recalled and searched by counsel for all known references.

It was crucial to develop a uniform method of measuring, forecasting and reporting progress for all the studies and of the management consultant's work, including the Consultative Environmental Statement. To process such vast amounts of information and use it to review current and future status, the solution had to be capable of maximising the storage and transfer of information during and after the studies. A Local Area Network of computers in the core team was established, which gave them all electronic access to time, cost and resources management, database, word processing, and graphics, from the overall study position down to individual activities within a particular study. Software was chosen for its ability to view the current position and forward forecast future trends, and for its ability to receive and transmit information electronically.

In parallel, a standard specification to be used in the tenders with the specific scope of each study was developed, to ensure uniformity across all 46 studies of monitoring, forecasting, reporting and formatting of output. By developing this, Arups were able to integrate the specialist technical contractors' progress reporting with their own to further report to BNFL. A four-weekly cycle of monitoring and reporting, was implemented throughout the three years of Phase 2.

The result was a very powerful management tool, able to consider any time, money or resource aspect of any activity in any individual study, and then to forecast its implications for the particular study, other associated studies and the overall completion of the Consultative Environmental Statement as well as Phase 2 itself. This enabled the Arup management team to consider future time and cost trends and, where necessary, implement corrective action plans to ensure the overall programme stayed on track.

Environmental studies

It is BNFL's policy, as expressed in the company's Environmental Policy Statement, to reduce the effects of its activities on the environment to a practicable minimum. Within this context, Arups' environmental studies had three main objectives:

- *to aid the selection of preferred infrastructure options*
- *to optimise selected options in order to mitigate or minimise the environmental impact of the proposals*
- *to undertake detailed assessments of environmental impacts of the proposed power stations and their associated infrastructure.*

The studies covered all of the topics required by the relevant national regulations and were carried out through individual contracts comprising a total of 27 separate studies covering both sites.

12 of the studies covered ecological topics, reflecting the proximity of both sites to ecologically sensitive areas such as the Solway Firth and River Annan. The former is one of the largest continuous areas of intertidal habitat in Britain and is designated as a Site of Special Scientific Interest, a Special Protection Area and a Ramsar site.

It is a particularly important area for waders and wildfowl: significantly, the entire breeding population of Barnacle Geese from Spitzbergen winter along the shore of the estuary.

In addition to birds, the rare Natterjack Toad is found along the northern shore in significant numbers and there are extensive areas of saltmarsh. The River Annan is renowned as a salmon and sea trout river, supporting both river angling and commercial fishing; the spawning grounds of the river and its tributaries make a significant contribution to the maintenance of the total numbers of these fish.

The ecological studies were undertaken in two stages. The first involved extensive baseline ecological surveys, carried out over a period of two years, and designed to identify ecological resources in the vicinity of the proposed power stations and their associated infrastructure. The need to allow sufficient time to determine seasonal variations, plus the programming constraints imposed by the project, meant that it was necessary to commission the ecological studies within four months of the start of the project. These studies then ran concurrently with the infrastructure studies.

Due to the geographic extent of the proposed infrastructure at Chapelcross and the complexity of the ecological systems potentially affected by this power station, the ecological studies were split into two areas: the power station site and Solway Estuary; and the reservoir site and River Annan. The Sellafield development proposals were not as extensive or complex and therefore the ecological studies encompassed only the River Ehen floodplain, the coastal zone and the power station site itself. For each study area the surveys included marine, freshwater, terrestrial, and avian ecology.

The results of the baseline surveys were used by separate technical contractors to classify and characterise the ecology of the area and to undertake to following:

- *identification and evaluation of the important species, rare communities, and sensitive habitats within the study area*
- *prediction of the nature and magnitude of the expected impacts*
- *investigation of the structure and functioning of communities and ecosystems*
- *development of proposals to avoid or protect habitats, communities and species perceived to be at risk.*

In line with BNFL's Environmental Policy Statement, extensive habitat creation and enhancement measures are proposed to offset the effects of the development proposals. In addition to these measures a long-term Ecological Management Plan would be prepared by the operator of each power station to ensure that land affected by the proposals is maintained and developed with due regard to the conservation of natural habitats and amenity.

For example at the Water of Ae Reservoir site the proposed reservoir design and landscaping offers the opportunity for the creation of new wetland habitats.

It is proposed that a subsidiary dam be constructed on the western arm of the reservoir to create a shallow lake which would then be managed as a small nature reserve.

Discharges from the reservoir would be subject to rigorous monitoring, and appropriate control arrangements to ensure that the Water of Ae and River Annan, along with their important fish populations, suffer no unacceptable effects.The habitat creation and enhancement proposals have been developed in partnership with BNFL's landscape architects, and this involved extensive liaison between technical contractors. The supervision of this process was the responsibility of the Arup study managers who were also responsible for consultations with statutory consultees and other interested parties.

The final layout for each power station, and the form and massing of the buildings should BNFL proceed, will depend on which vendor is selected by BNFL to construct them.

Each one approached by BNFL as part of the selection exercise has offered their standard design in order to minimise the costs of construction.

However, it was recognised that the proposed power stations would be a major presence in the landscape and that due consideration must be given to layout, aesthetic and design issues. BNFL's landscape architects were commissioned to develop a generic design and layout. This study established a set of design principles which were also applied to the landscape design for each power station.

For the Chapelcross proposals the principles placed the reactor dome at the centre of concentric rings expressed by the use of landscape mounding and planting. The nuclear island (reactor and turbine hall) would be located at the centre of a rectangular grid, with cooling towers and other buildings arranged around it. At Sellafield the reactor would also be placed within a grid; however, landscaping and planting would be used to extend the appearance of the grid beyond the station site as part of the restoration proposals for the contractor's area.

The principles called for:

- *use of mounding and planting to provide a transition between the ordered grid and the informal features of the surrounding landscape*
- *use of building type and colour, and texture of external treatments, to reflect visibly the sophisticated nature of the processes of nuclear power generation.*

The use of planting in accordance with these principles also allows opportunities for screening so that only features such as cooling towers would be visible from critical viewpoints. Normally an Environmental Statement is made public when it is lodged with the application to which it relates. BNFL will not be in a position to decide whether to make a consent application until it has fully assessed the outcome of the Government's review of the future of the nuclear power programme.

Arups' agreement with BNFL required the production of an Environmental Statement for each power station, in advance of BNFL being in a position to define fully the scope of works to be included in the consent application. Given that any application was unlikely to be made until after 1996, any Environmental Statement produced in 1994 could need considerable amendment both to update data and to incorporate the details of the selected development.

For these reasons the document produced as part of the agreement with BNFL was termed a Consultative Environmental Statement. It is intended that the documents be used as part of BNFL's consultation process in the interval between completion of the Phase 2 Siting Studies of the Nuclear Generation Study, and the time when BNFL decide to proceed formally. The results of consultations based on this document would be taken into account by BNFL when finalising the proposals, should the decision be taken to make an application for consent to construct a power station.

5. Electric-fishing on the Water of Ae.

6. Widgeon on the Solway Estuary, about 5km from the Chapelcross site.

Infrastructure studies

CHAPELCROSS

• *Water resources - Annan and Kielder Catchments*

These studies investigated the available options for the supply of up to 110Ml per day of cooling water to a single reactor station. The Annan study looked at the development of a reservoir within the Annan Catchment to regulate flows in the river and to support cold water abstraction, whilst the Kielder study examined the various options for taking water from the currently under-utilised Kielder Reservoir and transporting it across the watershed to Chapelcross.

• *MOLF*

This study investigated the options available for the delivery by sea of up to 50 pre-assembled plant items of 750 tonnes maximum, associated with the construction of the power station. Loads would be brought by barge to a new berthing facility to be built on the foreshore, and loads transferred by road and purpose-built haul route to the site.

• *Transportation*

The transportation implications arising from the construction and operation of the power station, including likely sources of aggregates, etc.,were assessed.

• *Road and rail*

This study looked at the options available for linking the power station to the railway network for the movement of nuclear fuel flasks. The options included both direct rail links and the provision of a railhead with a suitable road connection to the station. Also studied were the improvements required to the local road network to cope with predicted construction traffic, including the abnormal loads of up to 750 tonnes brought in via the MOLF.

• *Effluent discharge pipeline (EDP)*

The options were assessed for the discharge of up to 21Ml per day of liquid effluents (predominantly cooling tower purge water) for a single station to the Solway Firth.

• *Cooling options*

This study investigated the available options for the provision of the necessary cooling for the power station, including wet, dry, hybrids, direct, and indirect cooling. The subsequent adoption of wet cooling using cooling towers necessitated the development of the various water resources schemes.

• *Marine*

A hydrographic survey was carried out for the whole of the Solway Firth. Marine numerical models were subsequently constructed of both the Irish Sea and the Solway Firth. These were used to model potential effects of various development proposals impacting on the Solway (MOLF, EDP,etc.).

SELLAFIELD

• *Flooding study*

The likely flooding regime in the River Ehen, which runs to the west of the site, was researched. Subsequently, options for flood alleviation were developed in order to protect the site from a 1 in 10 000 year flood event.

• *Seawater cooling study*

This study (described in detail elsewhere) looked at how to provide the necessary 63m^3/sec of cooling water to a single station via 6m diameter intake and outfall tunnels 1.8km and 2.5km out under the Irish Sea.

• *Transportation and MOLF*

As for Chapelcross, it was necessary to determine the effect on transportation infrastructure of the construction and operation of the power station, and assess whether pre-assembled plant items could be delivered by sea.

• *Marine*

A hydrographic survey was carried out for the Irish Sea off the Cumbrian Coast. Marine numerical models were subsequently constructed and used to model the effects of the various development proposals impacting on the waters off Sellafield (MOLF, cooling water discharges, etc.).

Infrastructure studies

The construction and operation of a power station has vast infrastructure implications, and the scope of the infrastructure studies and the context of their outcomes for each site varied enormously - from an engineering design for the Chapelcross Effluent Discharge Pipeline, comprising 8km of 600mm diameter pipeline in open countryside and under the River Annan with a submerged outfall in the Solway Firth, to the road and rail study, whose conclusions were followed by the design of a 1.5km rail spur from the West Coast main line to a railhead on a substantial embankment and the upgrading of 15km of existing roads. Details of the range of infrastructure studies are given above.

One of the initial tasks was to define the scope and prepare technical briefs for each study. This required a considerable range of technical expertise, drawn from specialist groups within the firm as necessary, to support the core team. Arups themselves won by competitive tender a number of the infrastructure studies, including the road and rail and cooling tower options studies at Chapelcross, and at Sellafield, marine off-loading facilities (MOLF), hydrographic survey, road and rail options, marine numerical modelling, and seawater cooling. Aerial photography was carried out over some 350km^2 of the north of England and southern Scotland. Subsequently a digital ground model and 1:2500 mapping was produced for some 180km^2.

Conclusions

This management consultancy appointment was both unique and extremely important for Arups. The close working relationship established between the project and client teams proved essential, where continuous exchange of information was so important as the many studies progressed and output became available for use by dependent technical contractors.

The complexity of the studies was matched by their number, generating a vast amount of technical information to be analysed and conclusions drawn, or the output to be used by the management consultant when drafting the Consultative Environmental Statement. Many of the studies impinged on the work of others, and this needed a careful approach by Arups to co-ordinating the work of the various technical contractors so that output from one study was delivered to the contractor for another in the right format and at the right time. This co-ordination also applied to the consultation process between technical contractors, statutory consultees, and affected third parties - landowners, nature organisations, highway authorities, local councils, etc. In many cases, output and co-operation from them was often necessary for a study to proceed. Arups liaised with and co-ordinated output from these different groups.

As a result of the Phase 2 study, completed on schedule in May 1994, it was established that it was technically and commercially feasible to build and operate a nuclear power station on each site. This was achieved and was in no small measure due to the dedication of the BNFL and Arup core team supported by many specialists from Manchester and other Arup offices.

References

(1) CURTIS, C. *et al.* Sellafield geotechnical study. *The Arup Journal*, *29*(4), pp.16-17, 4/1994.

(2) STROUD, M. *et al.* Sellafield cooling water system. *The Arup Journal*, *29*(4), pp.17-18, 4/1994.

Credits

Client:
British Nuclear Fuels plc

Management consultant:
Ove Arup & Partners Martin Broderick, Brian Campbell, Bob Carville, Allan Delves, John Grainger, Hakop Mirzabaigian, Paul Murphy, Peter Oldroyd, Keith Rudd, Fraser Smith, Rob Warren, (Manchester core team)

Simon Hill, Neil Jenkins, Paul Johnson, Roger Milburn, Richard Phillips, Corinne Swain, Paul Tomlinson, Ed Tufton, Mike Wilton (specialist advisors)

BNFL landscape architects:
Gillespies

Illustrations:
1, 4, 7: BNFL
2, 3: Denis Kirtley
5: Robert Warren
6: Jonathan Quinn/Wildfowl and Wetlands Trust.

7. Aerial view of Sellafield site.

Printed in England by Reedprint Limited, Windsor, Berkshire