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Arup is a global organisation of designers. It has a constantly evolving skills base, and works for local and international clients throughout the world.

We shape a better world

Front cover: the Acton Peninsula redevelopment, Canberra (pp3-11) Photo: John Gollings Photography

Back cover: The Imperial War Museum, London: Stage 3 (pp 42-47) Photo: Andrew Putler

The virtuosic architectural concept for the New Museum of Australia and the Aboriginal and Torres Islander Institute of Studies in Canberra required both an innovative structural approach by Arup, and the use of the alliancing concept between client, architects, and contractors, to deliver the project in time for its immovable completion date of March 2001 and to its fixed budget of A$155M.

Since 1997 a voluntary team of architects and engineers from Arup Associates and Arup has worked on this school, which will eventually cater for 750 pupils, in a remote corner of Northern India. Designed to have minimal impact on the surrounding environment, it uses appropriate local materials, employs solar panels to power lighting, and recycles water for irrigation.

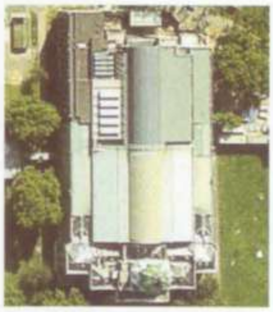
To improve the economics of platform installation and the practicalities of supporting topsides process facilities, Arup developed the ACE range of self-installing, moveable platforms for extracting oil and gas in water depths of up to 100m. The Hang Tuah platform, now operating in the West Natuna Sea offshore Indonesia, is the first built example of the concept.

The North East of England led the UK's new era of urban light rail transport when the Tyne and Wear Metro opened in 1980-84. Now, a new 18.5km extension has drawn the city of Sunderland to the south into the system. Arup was involved with the project for eight years, initially for the assessment of its environmental impact, and latterly as project facilitator and planning supervisor.

The Salt Lake City location gave the 2002 Winter Olympics the highest altitude speed skating arena in the world, where it was possible to use the elevation to create the world's fastest sheet of ice. Working closely with the architect, Arup saw the tight budget not as a constraint but as a springboard to give the Games and the City a LEED™-certified signature building for optimum athlete performance.

2654 Michigan soldiers died in the Vietnam War. The new Memorial in the State Capital, Lansing, records their names on 15 engraved steel plaques supported by a 120ft steel arc. Attached at one side to a concrete plinth, the arc is suspended on the other side from a system of stainless steel cables and connectors developed by Arup, who also acted as electrical engineers for the project.

The Johannesburg Earth Summit has focused world attention even more closely on sustainability issues. This article outlines progress in the UK towards reducing transport demands and facilitating non-car modes, in the contexts of financial incentives, use of IT and other advanced technologies, and integration of land use and transport planning.



Arup Associates has been involved with the Imperial War Museum for nearly 20 years, developing its 19th century premises into a world-class home for the national collection. The third and final stage of the project embraces new educational and conference facilities, and a further major expansion of the Museum's exhibition spaces to accommodate its Holocaust Galleries.

NMA and AIATSIS: the Acton Peninsula redevelopment, Canberra

1. Main Hall of the National Museum of Australia: elevation to the perimeter of Acton Peninsula.

Pippa Connolly

The Alliance process

To achieve completion by the immovable date of March 2001, and with a fixed budget of A$155M, a construction Alliance to deliver the project was formed by the ACT government, arm.rpvht, Bovis Lend Lease, Anway, and Tyco Honeywell, with other sub-Alliance partners and specialist consultants, plus other team members. This arrangement, the first example of an alliance being used to deliver a building rather than an infrastructure project, was in place by the end of design development.

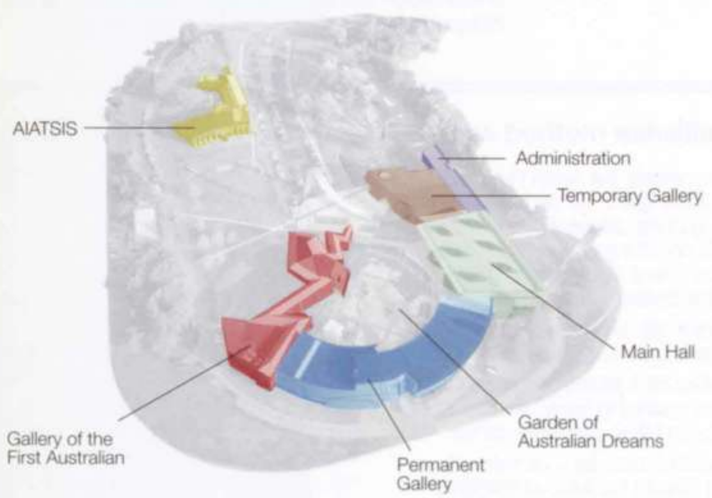
Arup was able to draw on the significant experience of the Wandoo project[1] and the alliance process, to evaluate its part therein and provide input. When the Alliance was formed, Arup had completed the structural design development, so was employed by the Alliance as a specialist consultant for structural design and performance-based fire engineering to the project's completion. The way the project was designed and delivered was unusual in almost every aspect, challenging all preconceptions of how a major public building would normally be delivered in Australia, not least in its very short timescale and rigid budget. The resulting buildings are highly unusual and striking, and have proved immensely popular. The quality of the project has also been recognised by numerous awards, and it was visited by the Queen in 2000 on her visit to Australia. This article describes some of its more unusual aspects.

The brief

At the time of the competition in 1997, the following requirements were outlined in the project brief:

Cultural and community precinct

- the site to be developed with a focus on community access
- each institution to be designed to be as welcoming as Acton Peninsula itself
- the Peninsula to be open to all those who wish to enjoy it, whether or not they visit the Museum or the Institute
- the ACT community, and visitors to Canberra, to be able to experience an extensive range of recreation and entertainment facilities, including an amphitheatre, dining facilities, waterfront access, cycle paths and picnic areas, with outdoor areas enhancing the overall cultural experience for visitors
- the appeal of the site to be increased, with some 'all hours' facilities independent of the institutions' ticketing and hours.



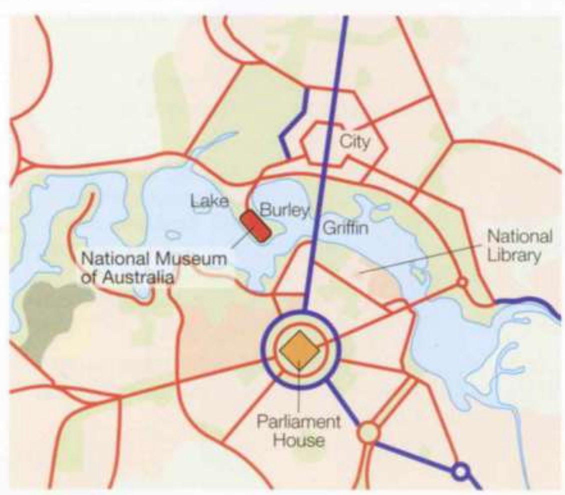
2. Principal buildings on Acton Peninsula.

Introduction

The Acton Peninsula Redevelopment project is a group of new buildings on the 11ha Acton Peninsula in the man-made Lake Burley Griffin, Canberra, ACT, Australia (Figs 2 & 3). They house the National Museum of Australia and the Aboriginal and Torres Strait Islander Institute of Studies.

The Museum was created by an Act of Parliament in 1980, so for many years it was an institution without a home, various sites being considered before Acton Peninsula was selected in 1996.

Then, the government decided to construct the Museum as the flagship project for the Centenary of Federation in 2001, and an international design competition was held in 1997 and won by Melbourne-based architects Ashton Raggatt McDougall in joint venture with Robert Peck Von Hartel Trethowan (arm.rpvht), supported by Arup for structural, traffic, and performance-based fire engineering design.



3. Location plan.

National Museum of Australia

- to research Australian history, develop a national collection of historical material, create exhibitions and public programmes exploring the nation's heritage and history, and make it accessible to all Australians
- the 16 000m² (net) building to allow the institution to operate as a fully-fledged national museum, with around 5000m² of exhibition space including the 'Gallery of the First Australian', and a 1500m² Main Hall / exhibition space plus another 1000m² for temporary exhibitions
- to house an information and resource centre, offices, a media facility with broadcast / telecast studio, a restaurant, café and shop, and some spaces available for hire
- to incorporate a 1000m² digital theatre
- to incorporate a sophisticated media and communications centre able to exchange data with schools, museums, and other institutions around the world
- to combine the best contemporary exhibition techniques and state-of-the-art technology within a dynamic architectural space to create a unique visitor experience
- to be a place all Australians can call their own
- to accommodate visitor projections of 315 600 people per annum, of which 39% estimated to be children.

AIATSIS

- to maintain AIATSIS as the premier research institution and centre of knowledge for Australian indigenous peoples, with its international reputation for excellence in research, learning and collecting
- to preserve and disseminate information about Aboriginal and Torres Strait Islander cultures and societies, both past and present
- to be of approximately 4000m² total area
- to house the Institute's library, Aboriginal Studies Press, research facilities, exhibition area, and administration
- to be designed and located on the Peninsula to clearly reflect its independent status and function.

The buildings

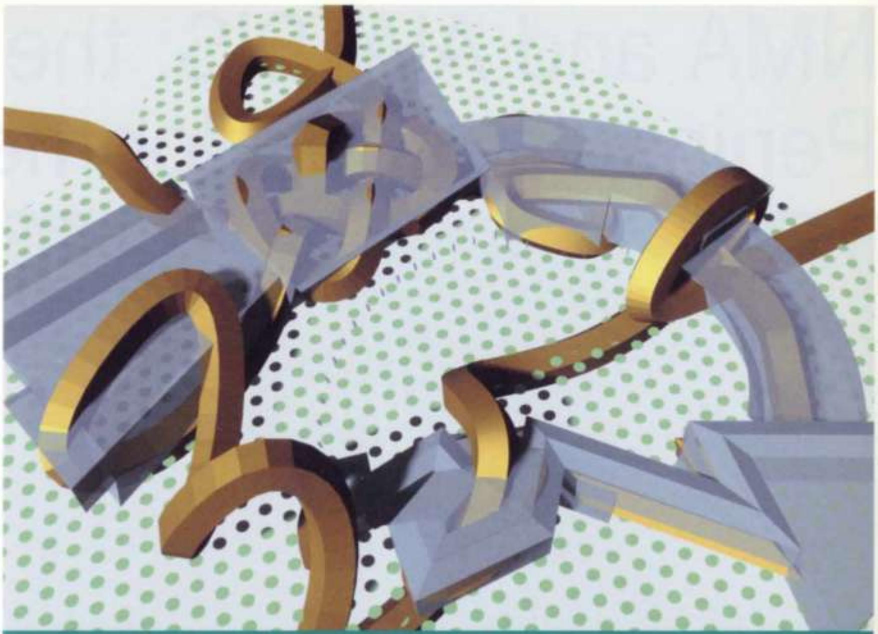
Overview

To avoid a single monumental structure, the architectural design placed the main Museum buildings in a C-shape within the Peninsula shores.

The NMA encloses a central 'Garden of Australian Dreams' - an integral part of the exhibition spaces - whilst the AIATSIS building is placed separately from the Museum, emphasising its individual identity.

The Museum itself comprises five distinct areas, (see Fig 2 on previous page):

- The Temporary Gallery: clear span spaces to international exhibition standards, accommodating travelling and temporary exhibitions
- Administration wing: accommodation for the museum staff, the broadcast studio, teaching spaces, and plantrooms
- Main Hall: a multi-use vaulted space, lakeside restaurant, and shop (and the main entrance to the Museum)
- Permanent Gallery: permanent exhibitions, teaching spaces, a café, library and the 'Four Corners' theatre (in which rotating seating in the centre turns visitors, having entered via one corner, through a series of exhibits in the three remaining corners); significant additional space in extensive mezzanines; all areas incorporating a mixture of interactive and static displays.
- 'Gallery of the First Australian': exhibition space for the aboriginal collection, plus back-of-house curatorial areas and more plantrooms.



4. The invisible rope that binds together the architectural concept.

The key architectural concept for the site incorporates a symbolic 'rope', of pentagonal cross-section, which winds around the buildings and gardens as if 'tying together' the disparate strands of Australian history (Fig 4). This 'rope' is mostly invisible, but it does make several significant appearances both within buildings and externally, and it was these locations that provided the most challenging geometry for Arup in the structural design.

The remaining areas of the Peninsula have been landscaped and connected into the parklands that line the shores to Lake Burley Griffin. These form a valuable community resource, containing a 2000-person outdoor amphitheatre and lakeside walk / cycle path (also the indispensable Australian coin-operated BBQ!).

The alliance method and its effects on engineering delivery

As noted already, the Acton Peninsula project is thought to be the first instance of a building being delivered by an alliance - in which most things are done in the same way as in a hard money contract, but with some crucial differences:

- All parties sign one agreement - there are no side agreements.
- All parties have representatives on the Alliance leadership team, who must be able to bind their respective parties.
- All decisions must be unanimous; there are no dispute resolution procedures.
- All parties are assured of receiving their direct costs (salaries and out-of-pocket expenses).
- All parties put their normal overhead and profit (OH&P) at risk against a set of reward and risk curves, which vary above and below the benchmark of 'business as usual' (BAU).
- If the Alliance does a better-than-BAU job, as defined by the risk / reward, the parties receive a better-than-BAU OH&P - but the reverse may also apply.
- Risk / reward curves differ markedly to suit different projects.
- A comprehensive selection process is required to put the best people in place, before price is even discussed.
- The agreement must be constructed so that the only possible outcomes are win / win or lose / lose. If win / lose is possible, the agreement is wrong.

This approach helped the engineering solutions to be developed to suit preferred construction methods, and significantly reduced decision times on certain elements.

An example of this was when the foundation system for one building was changed completely in 24 hours to respond to ground conditions encountered.

The Alliance had chosen a short bored pier solution, bored through a 2m+ high, fully engineered fill platform. Once on site the first bores all hit 'floating' boulders in the existing ground. This was always a potential risk, but the decision had been made to proceed on the basis that the risk appeared to be small of hitting many boulders, particularly so early in the foundation construction.

An option to use high-level pads in the fill platform was investigated, with a full redesign available in 24 hours. An unusual feature was that it incorporated circular pads as these could be constructed using boring equipment already on site.

This option was costed and immediately adopted, enabling work to proceed without any delay or cost penalty.

Complex geometry/ 3-D thinking

This project presented numerous engineering challenges, which were overcome by the design and construction team to deliver it on time and within budget. One of the biggest was to structure the geometrically complex buildings.

Early in the design, the Arup team realized that the optimum structure needed to be generated from, and integrated into, the architectural concepts. There is hardly one piece of structure not at some sort of angle, and with very little apparent symmetry or repetition. Despite this, some basic rules could be, and were, adopted for the structural approach to deliver the architectural intent. It needed to be simple to construct and cost-efficient - directly opposed to the option of producing a 'regular' structure from which the architecture would 'hang off' on extensive secondary structures. This key decision influenced all work on the project, and from it stemmed the need for the Arup team to visualize all the 3-D spaces left between the façade and the internal finishes that could house the structure and generate the architectural form. This in turn led to:

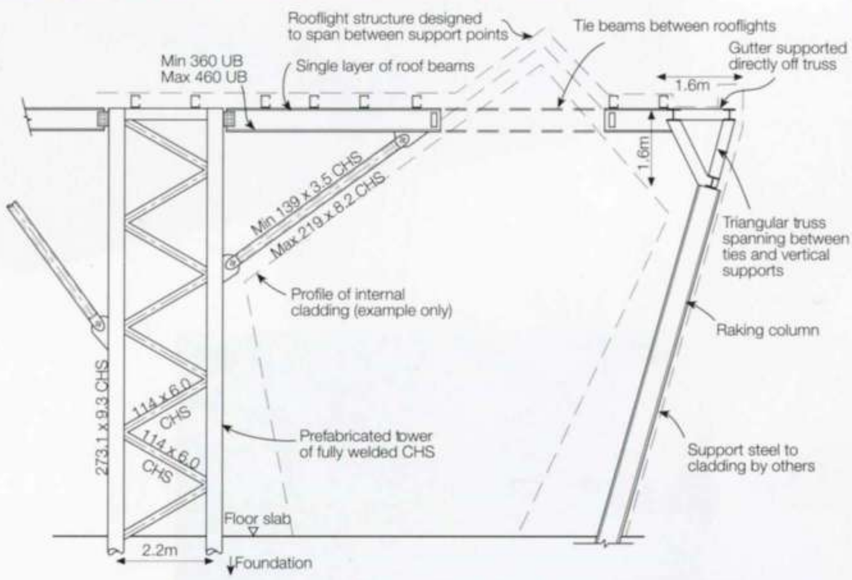
- developing a cost-effective scheme for the structure to each building
- defining the geometry of the structure with sufficient accuracy to allow analysis of the forces using Arup's own in-house software, GSA
- designing the thousands of individual members for the appropriate forces and re-analysing for deflection, again using GSA
- defining the geometry again with greater accuracy to produce construction documents
- determining the exact relationships of members at joints to facilitate connection design and detailing.

The five distinct areas of the NMA each presented different challenges. Outlined below are some examples of innovation and engineering quality in each location, as well as overall philosophies.

Computer use to best advantage

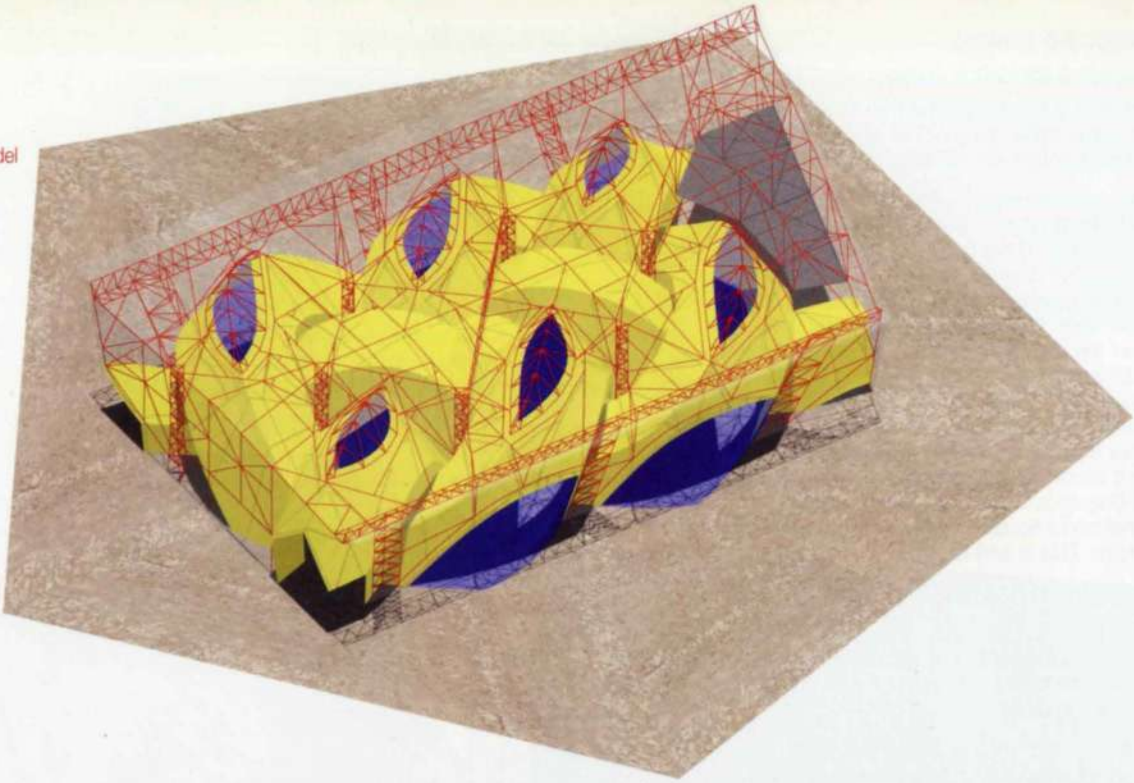
The team made full use of computer-generated models to match structural geometry to architectural intent, with models generated by the architects being constantly swapped and compared with structural models prepared by Arup using GSA. The basic steel structure was conceived as a simple arrangement of beams and columns utilizing basic connection techniques (Figs 5-7). Taking this simple philosophy and working it into a 3-D setting achieved the geometrical shapes, and close collaboration with the fabricator made it possible to design the structure to suit preferred fabrication techniques. Much of the building leans in different directions, so particular care was required to ensure stability through the general principle of using cantilevered towers.

5. Basic structural principles (a typical structural tower is on the left).

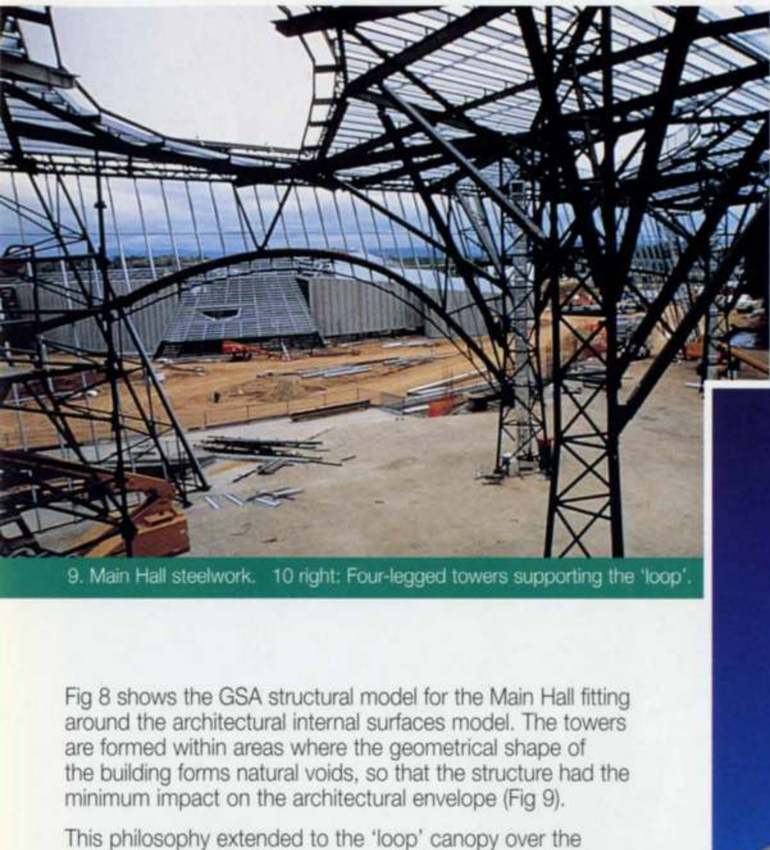


6 left: The first Main Hall tower on site.

7 above: Foreground: Temporary Gallery structure (in unpainted steelwork, for cost saving) awaiting erection; in the background is the first Main Hall tower.



8. GSA structural model in red; architectural 'internal surfaces' model in purple/yellow.



9. Main Hall steelwork. 10 right: Four-legged towers supporting the 'loop'.

Fig 8 shows the GSA structural model for the Main Hall fitting around the architectural internal surfaces model. The towers are formed within areas where the geometrical shape of the building forms natural voids, so that the structure had the minimum impact on the architectural envelope (Fig 9).

This philosophy extended to the 'loop' canopy over the main entrance (Fig 10), the major stabilizing elements of which are two four-legged towers incorporated in the loop geometry at either end of the main loop. These are stable in their own right and provide the springing point for the main arch - as well as a stable construction sequence.

Challenging foundation conditions – varied solutions

Across the site the foundation conditions were highly variable. This required a considered engineering response to each specific situation, the solutions ranging from simple pad foundations to short bored piers, the use of engineered fill, platforms and rafts.

The AIATSIS building (Fig 11) required more than one solution in its footprint due to this variability. The site is underlain by a sequence of approximately 3m of uncontrolled fill, 1.5m of very loose, water-charged sand hydraulically connected to Lake Burley Griffin, 3-4m of very stiff to hard sandy clay, and then layers of sand, gravel, and clay to weathered rock at unknown depths. The fill and sand layers diminished in thickness across the site, giving variable founding conditions with no well-defined boundaries. Foundation options considered included bored piers founded in the very stiff to hard sand, driven piles founded in the same, pad footings founded in a controlled fill platform, and a raft founded in a controlled fill platform.

11. AIATSIS building.

The Alliance's least-risk solution was a raft foundation for the more heavily-loaded east wing and pad foundations for the central and west wings where loads were lighter, both founded in a controlled fill platform. Construction of the latter involved removing all existing fill material and loose sand and replacing it with controlled fill on a layer of gravel and geotextile reinforcement.

This method proved very efficient, as it could proceed with the highly variable founding conditions, without affecting the programme.

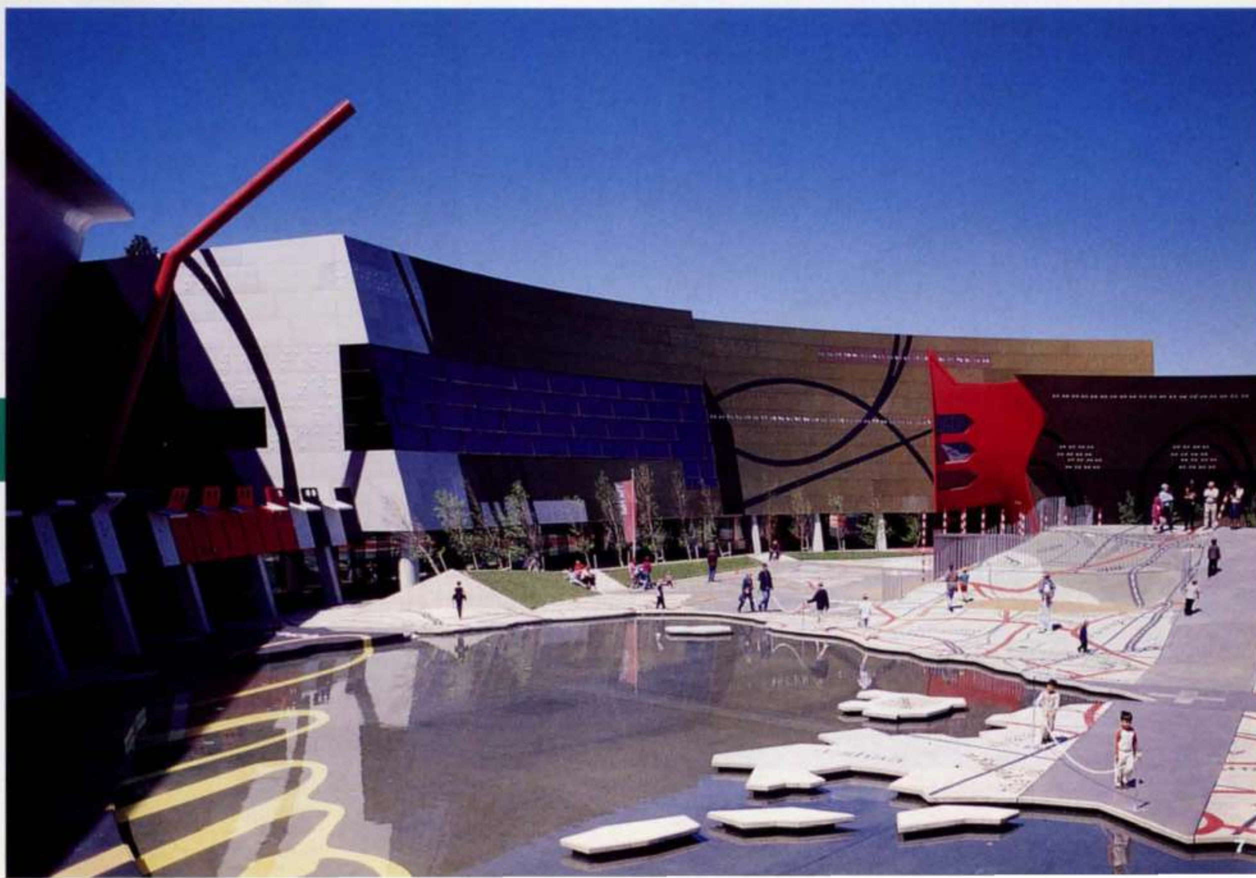
Permanent Gallery cladding

The Permanent Gallery is the Museum's primary display area, and with the rotating 'Four Corners' theatre forms the hub of the development. With its 120m curved façade broken in the middle by the pentagonal rope looping through the structure (Fig 12), it forms a striking backdrop to the Garden of Australian Dreams (Fig 13).

Deep purlins, spanning the two-storey clear height of the building, support the external and internal walls, providing an easier set-out, allowing for the building's horizontal curvature and leaning walls and a cost saving on internal fit-out. It also allowed for a major reduction in secondary steelwork by using a single element to support both internal and external surfaces, while incorporating all the steel columns within this wall zone.

12. The pentagonal 'rope' becomes visible in the middle of the Permanent Gallery.

14. 'Loop' canopy and main entrance tunnel.



13. The Garden of Australian Dreams enclosed by the Permanent Gallery.

15. Main entrance 'tunnel'.

Main Hall skylights

The six skylights in the Main Hall each consist of two curved tubular trusses with a common top chord (Fig 17). The largest skylight is some 22m long and weighs 7.5 tonnes fully glazed. They were fabricated on site (Fig 18), glazed, and then lifted into place on the roof by a single 200 tonne crane. This eliminated the occupational health and safety issues of working high, and allowed them to be constructed simultaneously with the roof structure. To eliminate stresses induced by deformation of the roof, each skylight is supported at three points only, allowing it to move with the roof in a similar manner to a three-legged stool. Detailed analysis of all stages of erection, again by GSA, ensured that the glass and cladding would not be damaged as the skylights were lifted into place and would deflect in various ways before attaining their final deflected shape.

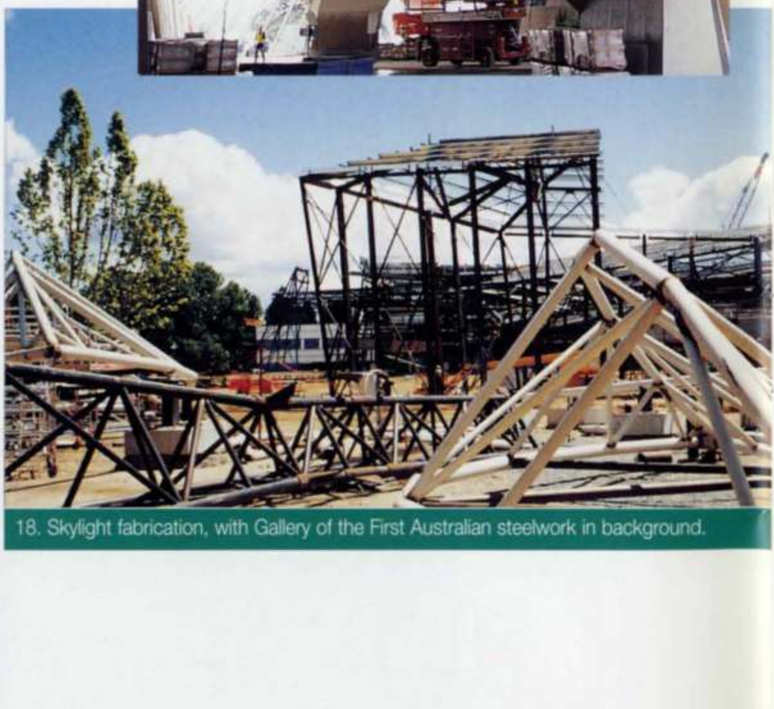
Temporary Gallery and administration building: forming the 'rope'

The Temporary Gallery building is the introduction to the Museum, and is used for displaying short-term exhibitions loaned by outside institutions. By the main car park, the public encounter first the building's 12m cantilevering roof and hanging wall. From this vantage point, a feel for the invisible pentagonal 'rope', as yet unexplained to visitors, can be gained as they are drawn into the half tunnel which sweeps dramatically down from a pentagonal skylight within the cantilevered roof and runs along the entire southern face of the building (Fig 15).

The position of the pentagonal rope essentially isolated the building's south-west corner. Within the space left by the cut of the rope, the structure had to form much of the support for the cantilevered and hanging roof as well as provide lateral restraint. A braced tower with square hollow sections (an example of the principle of using cantilevered towers noted already) was adopted in this space. !t uses as much of the footprint area as possible, thus enabling a lightweight solution that provides the required vertical and lateral stability. The tower itself was designed to be prefabricated in two major segments, allowing for easier and faster erection.

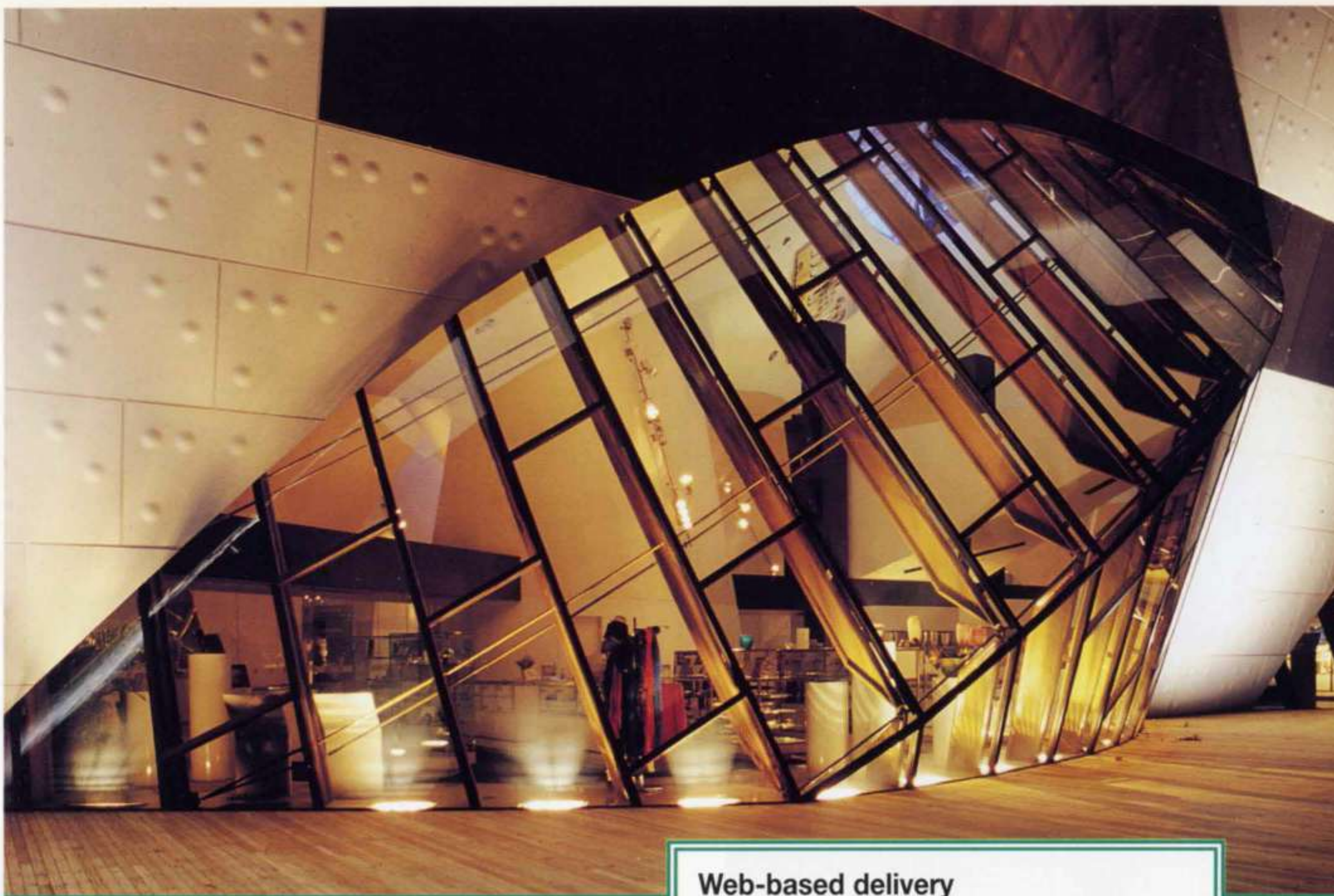
The rope surface itself was formed from thin steel sheet on a steel-framed backing (Fig 16). The sheet was cut into segments to allow for site handling, and each segment initially bolted via threaded studs to the ribs. The joints were then welded and ground back for as smooth a finish as possible, while providing an effective weather seal.

17. Skylight in the Main Hall.



18. Skylight fabrication, with Gallery of the First Australian steelwork in background.

16. Prototype of steel cladding for 'rope' surface.



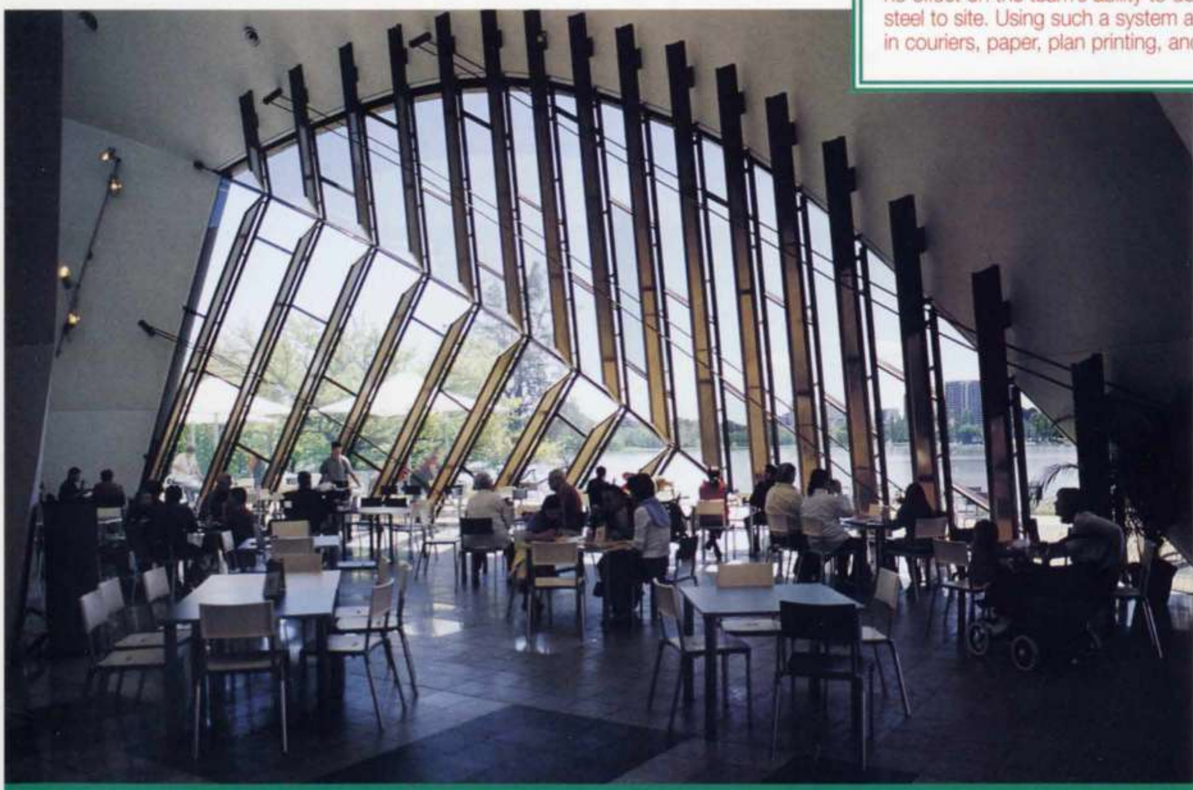
19. Window to Main Hall: echoes of Sydney Opera House.

One feature of the Main Hall is that where the imaginary pentagonal rope bursts out of the nominal box forming the Hall walls, bulging windows are created. These echo the Sydney Opera House glass walls, so Arup was ideally placed to draw on the experience of designing those [2 & 3] to assist in detailing the new structures efficiently and strikingly (Figs 19 & 20).

Web-based delivery

Information technology was used to full advantage, the whole project being delivered using Bovis Lend Lease's 'Project Web' facility. All team members published drawings and correspondence on an extranet, enabling them to work in many locations to deliver the project; Arup was the first consultant on the team to embrace the technology fully and be 100% up-and-running.

The steelwork shop drawings exemplified the web's effectiveness. They were prepared by detailers in Young (New South Wales), Perth, New Zealand, Melbourne, and Queensland, checked in Melbourne and Canberra, and fabricated in Young and Queanbeyan, NSW. Everyone involved drew all their information from the project web, which meant that physical locations had no effect on the team's ability to deliver the fabricated steel to site. Using such a system also saved significantly in couriers, paper, plan printing, and archiving.



20. Main Hall lakeside restaurant, with 'Sydney Opera House' window.

21. Visible expression of the centre of the imaginary pentagonal 'rope' protruding near the junction of the Main Hall and the Permanent Gallery.

Performance-based fire engineering: an ACT first

Arup Fire was appointed as principal fire engineer for the project, the Museum being the first major project in ACT to use fire safety engineering under the new building code.

Arup's international expertise came into play and fire safety engineering formed a key part of the design, addressing in particular the following areas, which allowed the full expression of the architectural intent to meet the client's brief:

- omission of fire compartmentation; use of suppression and smoke management allowed large open exhibition spaces, which would not otherwise have been possible (Fig 23)
- valuable artifacts in sensitive areas given high degree of protection by use of smoke management, fire compartmentation, and detection and suppression systems
- omission of fire rating to the steel structure supporting the mezzanine floors, allowing fuller expression of the structure and providing increased exhibition space
- reduction of fire rating of steel structure in back-of-house areas, allowing ease of construction and releasing funds for other aspects of the project
- omission of sprinkler systems to canopy areas with low fire load, providing cost benefits
- use of wall-wetting sprinkler protection glass systems in lieu of fire-rated glass, supporting the architectural intent to maintain sight lines and natural daylighting
- omission of sprinklers in the Main Hall, providing cost benefits to the project and significantly easing construction and on-going maintenance (Fig 24)
- use of smoke management to extend travel distances in the exhibition areas whilst still maintaining a high level of life safety
- omission of sprinkler protection in enclosed exhibition cubicles: detection and fire safety management providing extra protection to significant artifacts that could be severely damaged by sprinklers activated in the event of a fire or accidentally.

'The National Museum building was completed on time and budget and the valuable role played by Arup... was vital in ensuring that these targets were achieved. The standard of Arup's work and liaison with the Alliance responsible for the project was excellent.'

Dawn Casey, Director, National Museum of Australia

Lateral thinking for optimum solutions

The Acton Peninsula Redevelopment was no ordinary engineering challenge. It required lateral thinking to deliver, and co-ordination of all disciplines within the team was essential to realise the intention of the project. The floor boxes throughout the gallery areas were a case in point. These deliver power and data outlets, and meticulous co-ordination was required with all parties to locate them within the slab and allow for the flexibility that ever-changing exhibition layouts require. The floor boxes had to be simple to build, become an integral part of the floor finishes, but still be able to support fork-lift wheel-loading.

At the junction of the Permanent Gallery spaces, where the rope makes a dramatic cut through the buildings, the imaginary centre of its pentagonal cross-section shoots out of the ground and cantilevers 27m at 30° to the vertical and with a kink at its end. The architectural expression of this needed to be as slender as possible - and the steel tube structure proved to have an adverse dynamic response to wind. To stabilise the structure and still retain its slenderness, a chain mass damper was incorporated within the steel tube to adjust the structural response to the wind - maintaining the architectural intent without increasing the structural size (Fig 21).

The team also investigated in detail how to produce a concrete mix that would provide a multi-coloured finish suitable for polishing, without significant cracking. Ultimately the decision was taken to use applied materials for the floor finishes, but the slab composition, particularly for suspended structures, still needed to be as low shrinkage as possible to avoid damage to finishes. This was achieved through close collaboration with concrete suppliers and placers - not possible with a more traditional delivery method.

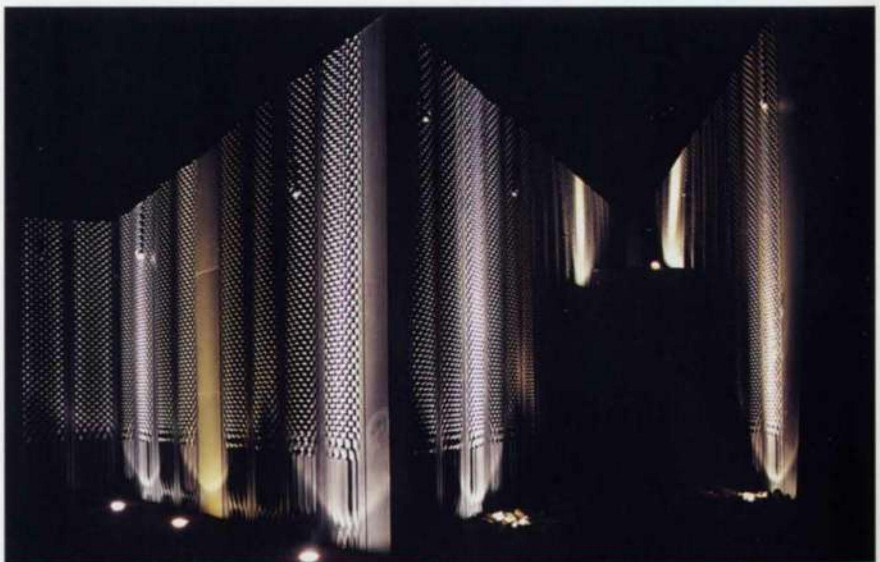
Effect of limited delivery time on working methods

The unalterable opening date of the Museum forced many normally sequential tasks to be done in parallel.

The major effect of this on the structural design was that it had to be completed without the architectural design being as well progressed as would normally be expected - and then to construct works on site with enough flexibility to accommodate the still-developing architectural design.

Arup thus had to design for flexibility without increasing costs, which could only be done by fully understanding both the architectural intent and construction constraints. This made communication absolutely critical at all stages. This was exemplified by the precast panels that clad the 'Gallery of the First Australian'. It was known that they would have some sculptural form and lean away from the building, but beyond that the steel support structure had to be designed and detailed to accommodate as many options as possible without putting unnecessary cost into the structure. Rules were established for the panel design that would give the architects flexibility in their design but still enable the support structure and foundation design to proceed efficiently.

The final result - striking precast concrete panels with an undulating finish - was made from moulds formed by computer-generated profiles. A prototyping process helped to refine the moulds and the design while the structure was still being erected (Fig 22).



22. Moulded concrete panels to the Gallery of the First Australian illuminated at night.

Conclusion

Visited by HM The Queen on her most recent Australian tour, the buildings were duly completed on budget and opened on time in March 2001 by Australia's Prime Minister, John Howard.

The Museum's virtuosic architecture, underpinned as this article has attempted to show by innovative structural design and delivery processes, is impossible to appreciate fully without being experienced at first hand. It is attracting major architectural awards and has already become the subject of a book-length study[4].

Finally, and most importantly, it is fulfilling its prime task of drawing and informing the public. In its first year the Museum has attracted over a million visitors.

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Awards

Dulux Colour Award Commendation, 2001

Australian Institute of Steel Construction Industry Innovation and Project Delivery Award, 2001
'Awarded for project delivery, allowing true integration of documentation, fabrication and construction in a building of highly irregular and unusual morphology.'

Master Builders Association National New Commercial Building Award over $10M, 2001, awarded to Bovis Lend Lease, Acton Peninsula Alliance for the National Museum of Australia

Master Builders Association National Partnering in Excellence Award 2001, awarded to Bovis Lend Lease, Acton Peninsula Alliance for the National Museum of Australia

IES Award of Excellence for Lighting Design, Meritorious Lighting Award, 2001

National Electrical Contractors Association, National Award for Excellence in Electrical Design and Installation, 2001 Best Project, awarded to O'Donnell Griffin

DuPont Antron Carpet Design Awards: Finalist Public Space/Retail, 2001

Blueprint International Architecture Award: Best New Public Building, 2001

Project Credits

Acton Peninsula Alliance members:
ACT Government (client)

Ashton Raggatt McDougall and Robert Peck Von Hartel Trethowan Architects, arm.rpvht (architects in joint venture)

Bovis Lend Lease (project management)

Tyco International (building services contractors)

Honeywell (security and building management system contractor)

Anway and Company (exhibition designers)

Sub-Alliance members:
National Engineering (structural steel)

G James (façades and glazing)

Urban Contractors (landscape)

Canberra Professional Equipment (audio-visual)

Specialist consultants:
Arup (structural, traffic, and fire engineering design)
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Bassett Consulting (building services)

Slattery Australia / Wilde and Woollard / Donald Cant Watts Corke (quantity surveying)

Room 4.1.3 (landscape architects)

Young Consulting (civil and hydraulic engineering)

TWCA (project managers)

Bassett Consulting, Eric Taylor and Associates (acoustics)

Vision Lighting (lighting)

KCLK (access consultants)

Taylor Thomson Whitting (landscape structures documentation)

Hughes Trueman (traffic detail design)

Mel Consultants (wind advice)

Peter Luzinat and Partners (building surveyors)

Coffey and Partners (geotechnical engineers)

23. Interior of the Gallery of the First Australian.

Illustration credits

1, 10, 11, 13-15, 17, 19-24: Richard Drew
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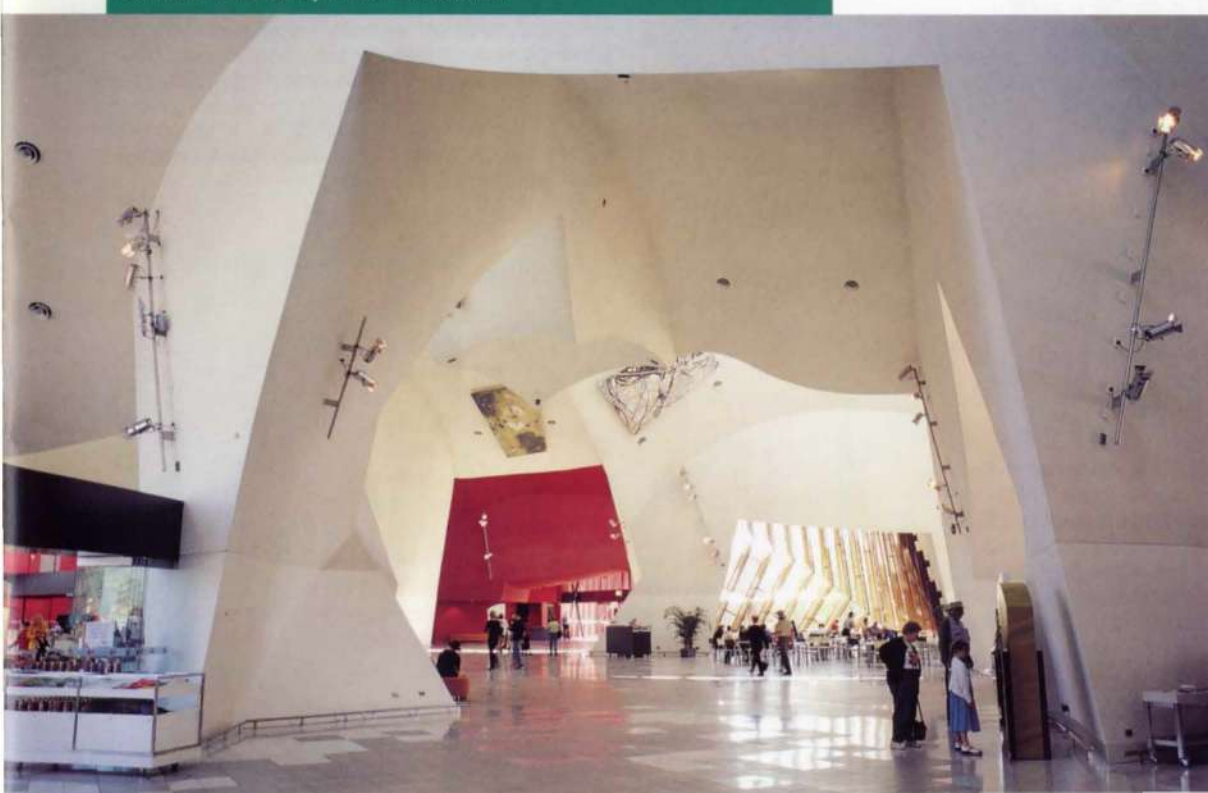
3: Sean McDermott
4: Ashton Raggatt McDougall
5: Daniel Blackhall
6, 7, 16, 18: Pippa Connolly / Barry Roben
8: Doug Wallace
9, 12: Photocall

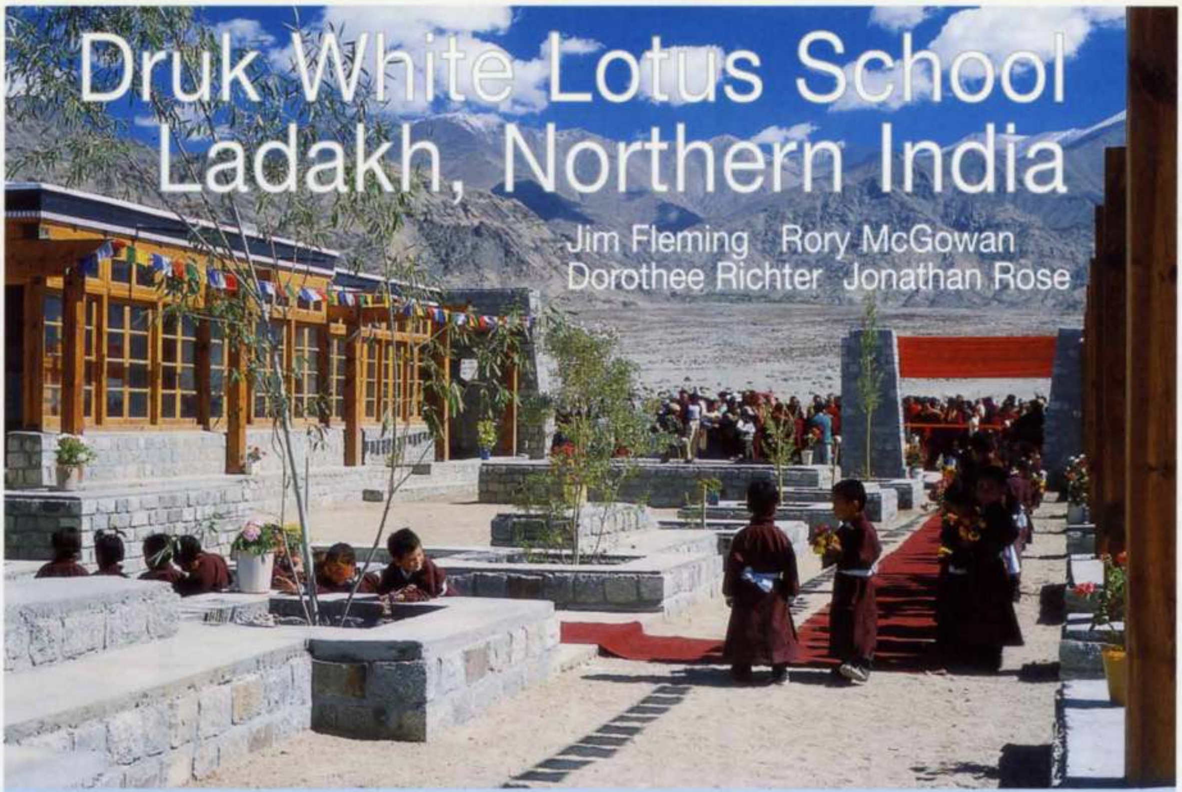


24. Interior of Main Hall.

National Museum of Australia Web link: http://www.nma.gov.au

Druk White Lotus School Ladakh, Northern India

Jim Fleming Rory McGowan
Dorothee Richter Jonathan Rose



1. Nursery and Infant School Courtyard.

Ladakh and its school

Sometimes known as 'Little Tibet', Ladakh is an ancient kingdom set high in the Indian Himalayas, close to Tibet's western border (Fig 2). This remote, high altitude (3500m+) desert is cut off by snow for around six months of the year, with winter temperatures dropping as low as -30°C in some areas. Yet in summer, the hot sun and snowmelt from the River Indus bring the rich, fertile valleys alive. The population is mainly Buddhist, with a minority of Muslims and Christians; for centuries, monasteries were the centres of learning, and the focus for the community's practical and spiritual needs.

The Drukpa Trust, a UK-registered charity under the patronage of His Holiness the Dalai Lama, has initiated the creation of the Druk White Lotus School.

Eventually to cater for 750 mixed pupils from nursery age to 18 years, the project is conceived as a model for appropriate and sustainable modernisation in Ladakh, providing a high quality environment for teaching and creating a living school community. It will offer a model academic curriculum combined with the needs of the local community, in a culture under enormous pressure to change. Though the project is a local initiative, it has an international context, with funding from charitable donations in the UK and Europe as well as the local community.

Arup involvement

A team of architects and engineers from Arup Associates and Arup has worked on the project since 1997, and is responsible for the masterplan, concept, and detailed designs of each phase of construction.

Every year, Arup gives leave-of-absence to an engineer or architect from the design team to be resident on site, to act as an 'ambassador' for the Trust, and to assist the local construction team and client committee.

Arup had several reasons for becoming involved in such a community project in a remote part of the world. When the people who were first approached visited Ladakh at the Trust's invitation, they were impressed by the ambition of the project and by the need for such a school locally. Also, some of these individuals had practical development work experience in Asia and Africa, and they realised immediately how Arup could make a real contribution to the project from the earliest stages.

2. Location.

Then, as the findings of field research were fed back to the UK and the initial design progressed, it became clear that the school could potentially have a wide influence, not just in the local region but also in contributing to the development of appropriate building technologies elsewhere in the world. The project was presented at the September 2002 Earth Summit in Johannesburg.

In terms of technical input, Arup has developed and uses powerful software tools that allow accurate analysis of issues such as the ventilated Trombe walls, the feasibility of using wool as an insulating layer, and the use of double-glazing. Such analytical tools were also used extensively in the daylighting studies. In addition, the design team had access to the firm's broader experience in seismic engineering, as many members have been involved in examining the aftermath of earthquakes, often in developing countries[1]. Lessons learnt elsewhere could thus be applied on this project.

The client's brief to develop a model school was ambitious, not only in terms of 'hardware' - energy, site infrastructure, buildings, material resource use, etc, - but also in 'soft' skills like building up the local project management team, establishing a cost database, and in optimising the use of local resources. All these initiatives aim to support the whole project as a demonstration of a new approach to teaching in such unique rural communities.

Trombe wall

Since ancient times, people have used thick walls of adobe or stone to trap the sun's heat during the day and release it slowly and evenly at night. Some buildings improve on this by incorporating a thermal storage and delivery system called a Trombe wall, named after French inventor Felix Trombe in the late 1950s.

The thick wall is coated externally with a dark, heat-absorbing material and faced with a single or double layer of glass separated by 100-150mm to create a small airspace. Heat from sunlight passing through the glass is absorbed by the dark surface, stored in the wall, and conducted slowly inward through the masonry..

Openings on the top and bottom of the thermal storage wall allow a convective heat transfer from the heated air cavity to the room inside, increasing the efficiency of the system.

Masterplan and ongoing construction programme

The school is in the village of Shey, around 16km from the main town, Leh, in the centre of the Ladakh valley. Close to the River Indus and its surrounding irrigated fields, the gently south-sloping, south-facing site will be steadily developed from open desert into a humane, well-scaled environment for children and teachers, and an important resource for the local community.,

The ecological context is fragile, so the site strategy aims to ensure an entirely self-regulating system in terms of water, energy, and waste management. There will be gardens and extensive tree-planting, and the related water infrastructure is drawn from a borehole by a solar-powered pump.

All the buildings take maximum advantage of the climate and the unique solar potential of the high altitude (3700m) environment. With the site encircled by peaks rising to over 7000m and overlooked by two important monasteries, the masterplan (Figs 3 & 4) aims to achieve a unique sense of place for the school buildings. The school building complex is organised within a nine-square grid and surrounding circle of a mandala, a symbolic figure of particular significance (though this underlying symbolic geometry will be less apparent on the ground).

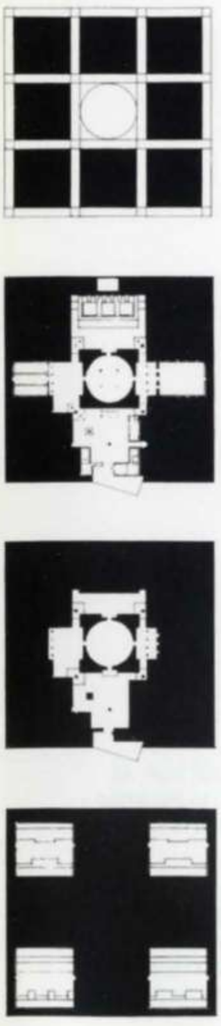
5. Construction in progress.

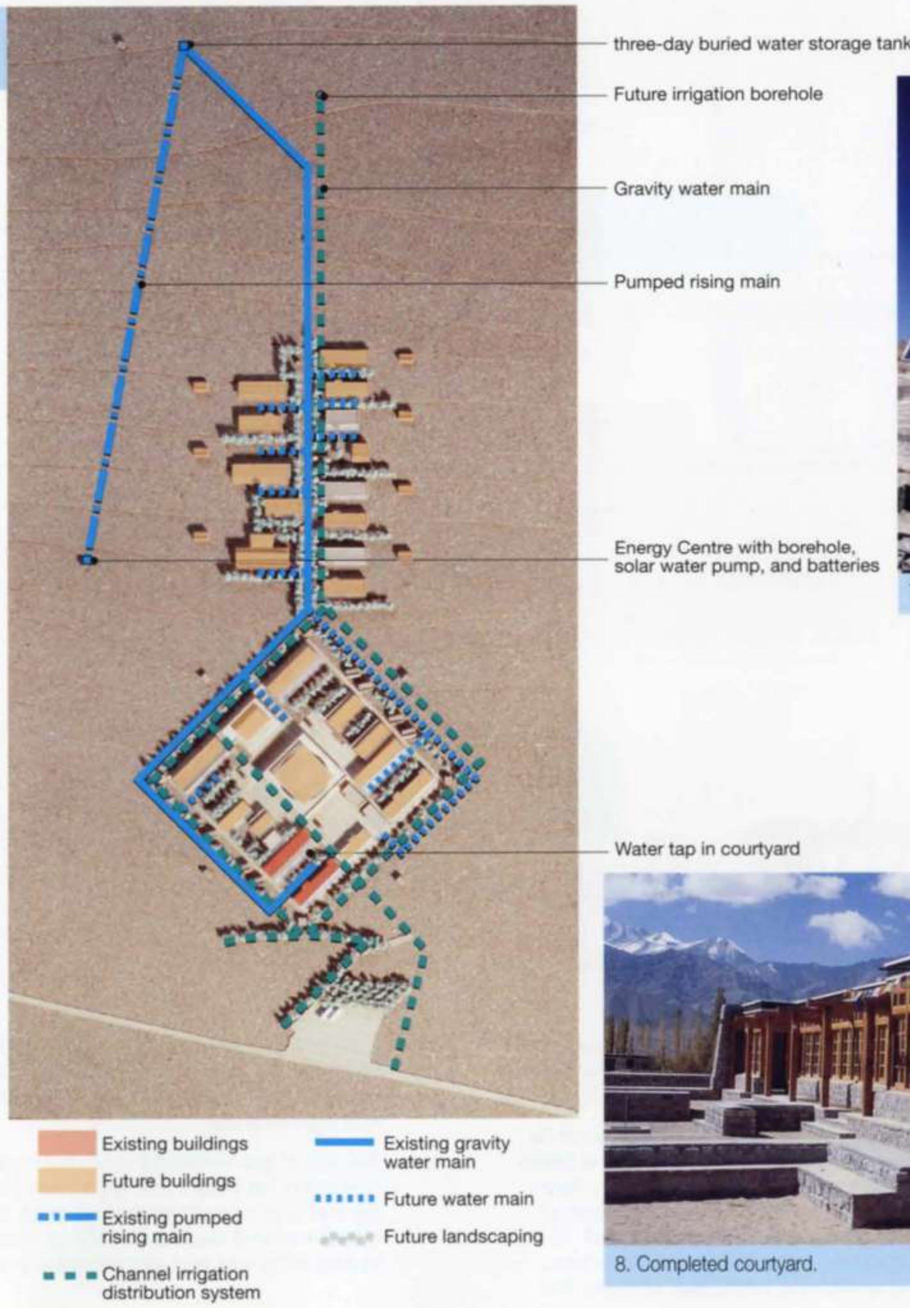
6. Laying the floor.

Typically, single-storey buildings are arranged around a series of primary and secondary routes in an environment not unlike a small village or a local monastery, standing in contrast to the surrounding open desert landscape.

There are four principal areas, interconnected but occupying the full extent of the site. The first, the site entrance and bus drop-off from the road to the south, gives pedestrian access to the second, the daytime teaching areas and the third, the residential spine rising to the north. The fourth area, comprising the water and energy infrastructure, is located separately alongside a service track to the west.

3 below: Plan development.
4 right: The masterplan.



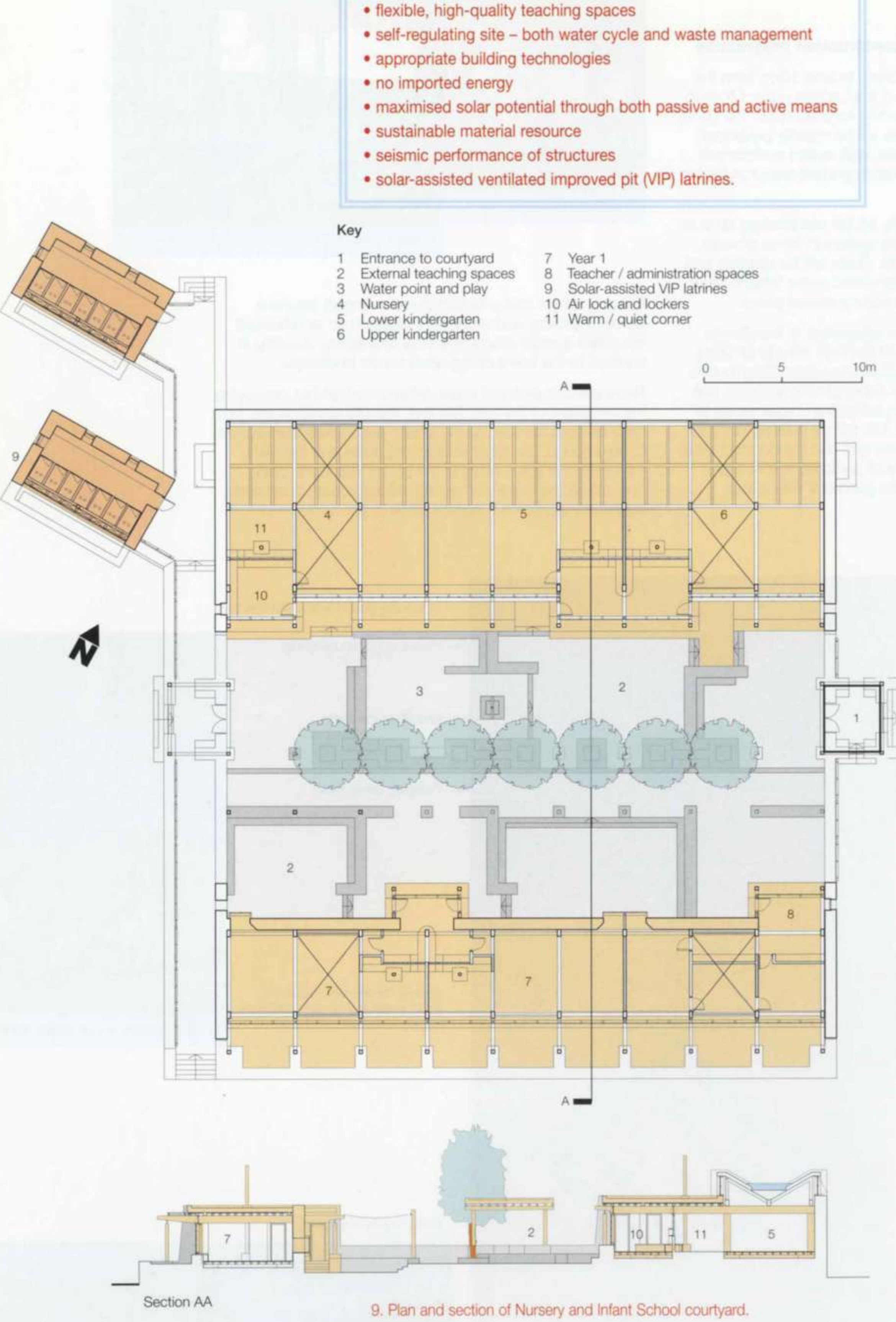


7. Solar panels power water pump.

8. Completed courtyard.

Key features of the design

- flexible, high-quality teaching spaces
- self-regulating site – both water cycle and waste management
- appropriate building technologies
- no imported energy
- maximised solar potential through both passive and active means
- sustainable material resource
- seismic performance of structures
- solar-assisted ventilated improved pit (VIP) latrines.

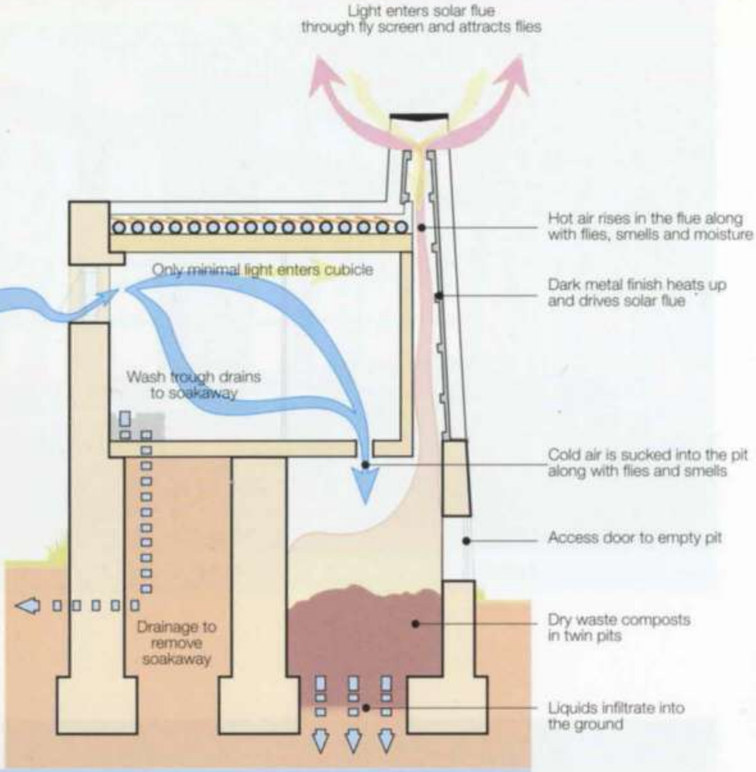


9. Plan and section of Nursery and Infant School courtyard.

Within the daytime teaching area, orientated 30° from south towards east to favour the morning sun, stands the already-completed Nursery and Infant School courtyard (Fig 9).

Also accommodated in the daytime teaching area will be three further teaching courtyards for the Junior and Senior Schools, the computer and science laboratories, a library and community resource facility, art studios, an open-air assembly courtyard, and a large multi-purpose hall. To the north along the residential spine will be a medical clinic, vocational training workshops, dining hall, kitchens, and residential accommodation for some pupils and staff. All buildings in this area are orientated due south to maximise solar benefit throughout the day and store heat for evening and night time use.

The first of four residential courtyard / gardens and kitchens to support the initial intake will be complete this year, using the first Trombe walls for heating small, eight-pupil dormitories and washrooms. The residential courtyards also include living area and accommodation for 'house parents'.



10. Section through VIP (ventilated improved pit) latrine. The dark south-facing façade, with the solar flue, draws air through the cubicle and pit, which avoids fly and smell problems.

11. Completed solar-assisted VIP latrine.

The Junior School courtyard is due for completion and occupation in 2004, timed to meet demand as the current intake of children reach Year 2. In parallel, new teachers are trained within the growing school community.

All the spaces and their structures are designed for flexibility, excellent daylighting and ventilation, active or passive solar energy collection, and to perform safely during earthquake. The construction materials - stone, mud mortar, mud bricks, timber, grass - are mostly indigenous to Ladakh, with careful auditing of sustainable resource supply. For example, the solid granite blocks used for all wall structures are formed and finished from stone found on the site or gathered from the surrounding boulder field.

The use of valuable soil resources is kept to a minimum in this desert environment, being either laid on tough grass over timber rafters for roofs, or formed into hand-made mud bricks in the village nearby. The latter are only used for the internal leaves of cavity walls.

Willow for the rafters is provided from monastery plantations nearby. Local expertise in craftsmanship, detailing, and the symbolic aspects of the architecture, is also fundamental in achieving the design intent. Taken together with the more sophisticated aspects of the design and the local materials used, the architecture points towards a contemporary and sustainable vernacular for the region.

Structural design

The key aspects governing the structural design were earthquake loading, durability and appropriateness. The kindergarten buildings have cavity walls on three sides with granite block in mud mortar as the outer leaf and traditional mudbrick masonry for the inner leaf; this gives increased thermal performance and durability compared to the rendered mudbrick walls commonly used. The Ladakhi style heavy mud roof is supported by a timber structure independent of the walls to provide the earthquake stability. The large spans needed in the classrooms, combined with the open glazed south facing façade and the high weight of the roof makeup, required large timber cross-sections and steel connections to ensure that they resist seismic loads and to warrant life safety in the case of an earthquake. These were difficult to procure locally, so the structural framing plan and connection details for the future phases have been altered to reduce timber section sizes.

Nursery and Infant courtyard (Phase 1)

The first phase of the school opened for teaching in September 2001, after three six-month construction seasons. This phase includes the Nursery and Infant School courtyard, solar energy centre, and water infrastructure. The Nursery and Infant School provides three large teaching / play studios for Nursery and Kindergarten years, two further classrooms for Year 1 children, and a small suite of rooms for the Head of School and administration.

These spaces are organised in two single-storey buildings arranged around an open, landscaped courtyard that will be used for external teaching during summer months and may eventually be covered with awnings made from parachute fabric, which is readily available locally. A water point is provided for wet-play, and deciduous trees are planted for shading. Just outside the teaching courtyard there are two innovative, solar-assisted, dry latrine buildings (Figs 10 & 11).

All classrooms are entered from the courtyard via a lobby (containing children's lockers for shoes), which provides a thermal buffer. Each classroom has a quiet / warm corner, with a small stove on a stone floor. Timber floors elsewhere and white-painted mud rendered walls are provided for maximum teaching flexibility in clear, uncluttered spaces.

Seismic considerations

Ladakh is highly seismic, classified in zone IV, the second highest category of the Indian Building Code. Although there have been no major earthquakes in recent times, Ladakh has frequent tremors. The January 2001 Gujarat disaster showed the lack of well-engineered earthquake-resistant buildings in India and the devastation that can result, so the client asked the team to develop a strategy for seismic engineering in the school buildings. It is possible to categorise the levels of structural protection against earthquakes as follows:

- limit response acceleration to acceptable levels for building users (maximum)
- limit response displacement to prevent damage to cladding and services
- limit response displacement to prevent damage to structure
- limit response force to prevent collapse and preserve human life only (minimum).

On this scale it is the minimum level of protection that is appropriate for this project, since human life safety is the priority and damage to the building fabric is acceptable to the client. The buildings that don't provide structural protection against seismic collapse are those without an accommodation function, such as toilet blocks, stores and entrance gateways. Those that do have a seismic-resistant loadbearing structural timber sway frame which supports the roof.

12. Timber structure to roof of lower kindergarten, optimising daylight.

Classrooms are designed for optimum daylight and passive solar energy collection, as there is typically no electric lighting or other source of heating. The design pays careful attention to natural cross-ventilation, passive shading and glare control, providing a teaching environment of very high quality, previously unknown in Ladakh.

The scale, the views into the courtyard, the environmental quality, and the no-frills construction process all contribute to the architecture, which stems as much from the simple balance of materials and craftsmanship available as from the need to get the most important things right.

This first phase has established the building pattern and language of detailing for the rest of the project.

It has been a huge learning curve for both the design team and local construction team, in terms of appropriateness of design, materials supply, understanding local construction techniques and local capacity, cost management, and overall project management.

Performance in practice and site feedback

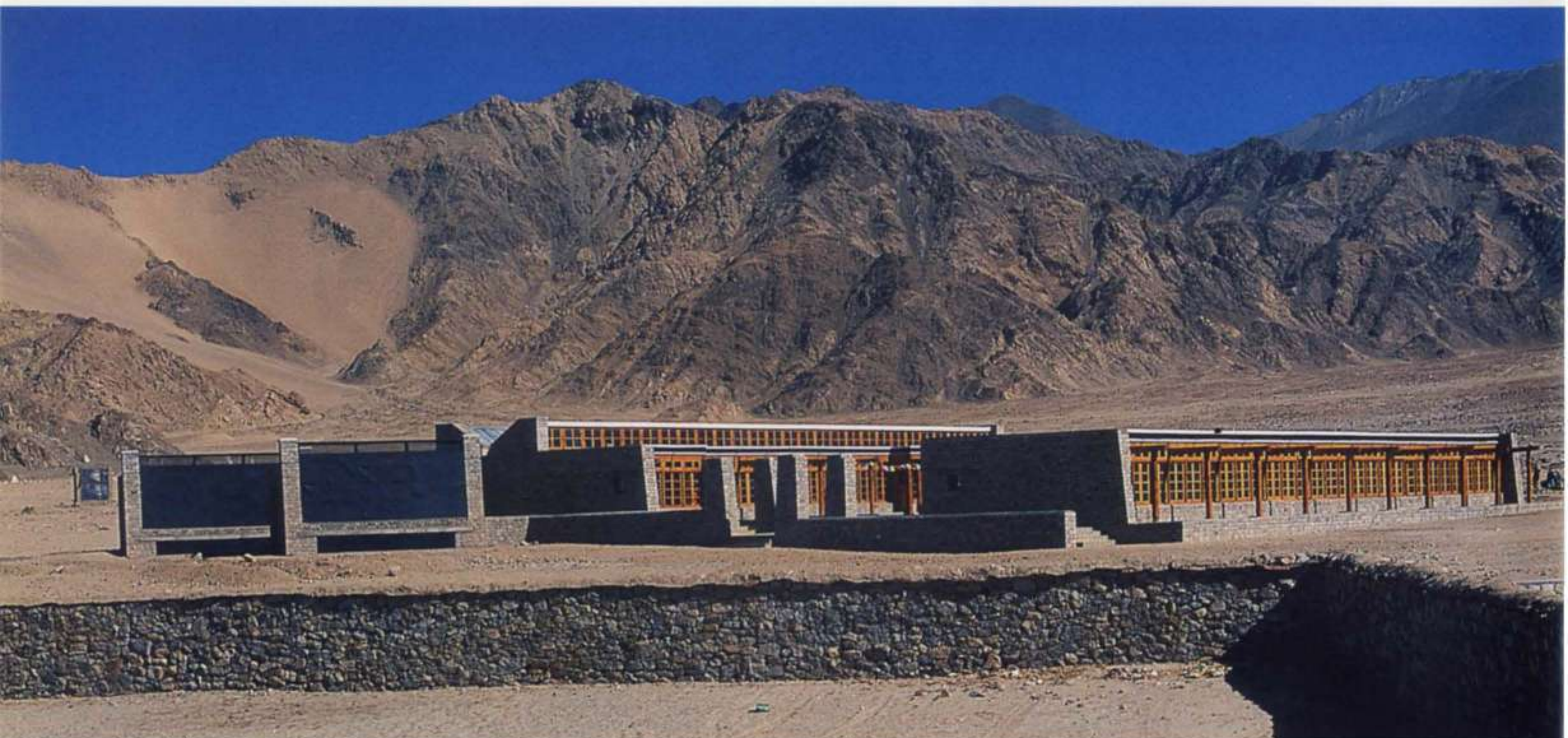
Construction will continue for up to eight years, with a senior design team member visiting at the beginning of the building season in April each year, followed by the Arup resident who typically remains on site for around four months from late June. With the Nursery and Infant School now complete and functioning, feedback is already being generated as to how these first buildings are performing, as well as the ongoing development of the teaching and learning community. The design team and the Drukpa Trust both look forward to a process of continuous learning about the school's performance in practice as it grows over the next few years, and feeding back the results of the lessons learned into the remaining construction work.

As well as other considerations, 'sustainable' for such a project means that the buildings must be constructed within local cost parameters. From a position of having no reliable cost information at the outset, the design team has established a cost database for budget management throughout the future detailed design phases and construction phases up to the school's completion.

Phase 1 was completed under budget and within acceptable local cost parameters - around 15% of the cost of a similar school in the UK. The team's aim is to further optimise expenditure, given the limited resources of the Trust and the balance of value between capital investment and a financially sustainable operating model.

13. Year 1 accommodation.

14. In teaching areas, timber cross-sections with steel connectors provide roof support.



15. The nursery and infant school as completed by September 2001, in its mountain setting.

16. Courtyard and mountains.

Conclusion

The ongoing debate on developing appropriate technology and solutions is crucial, and a project like the Druk White Lotus School particularly motivates the present generation of engineers and architects who want to work as part of teams looking at the much broader issues of sustainable development. Arup can make valuable engineering and architectural contributions to the most modest of projects, often in unforeseen ways, and from its many offices worldwide is ready to be involved in more projects like this - and already is. A professional approach to voluntary projects is vital for clear client / advisor relationships, and successful performance and delivery.

Reference

(1) CHAPMAN, T, *et al.* The British Earthquake Consortium for Turkey in Yalova. *The Arup Journal, 37*(1), pp49-52, 1/2002.

18. Local stone and timber: appropriate materials.

World Architecture Awards 2002

- **Best Education Building of the Year**
- **Best Green Building of the Year (Joint Winner)**
- **Regional Winner - Asia**

17. Painting the roof eave above timber-framed windows.

19. The pupils: Ladakh's future.

Credits

Client:
The Drukpa Trust

Designers:
Architects and engineers from Arup Associates and Arup:
Tony Broomhead, Omar Diallo, Jim Fleming, Francesca Galeazzi, Ian Grace, David Hsu, Richard Hughes, Karsten Jurkait, Gwenola Kergall, Sean Macintosh, Rory McGowan, Masato Minami, Barbara Payne, Roland Reinardy, Dorothee Richter, Jonathan Rose, Stephen Setford, Gopi Shan, Caroline Sohie, Stefan Waldhauser, Malcolm Wallace

Illustrations:
2-4, 9, 10:
Arup Associates / Arup / Sean McDermott
1, 5-8, 11-19: Roland Reinardy / Caroline Sohie

'As Project Director of the Druk White Lotus School, I have worked with Arup for over five years. Through their commitment and enthusiasm they have brought on board an excellent team of dedicated volunteer architects and engineers. Through their combined expertise the team has taken the design for the school forward, making the project possible and bringing immeasurable benefits to the education of Ladakh's children.'

Annie Smith, Drukpa Trust

Visit the project website at: http://www.ArupAssociates.com/DrukWhiteLotusSchool/Home.htm

Hang Tuah ACE Platform: Delivering a new offshore product

Gordon Jackson Brian Raine

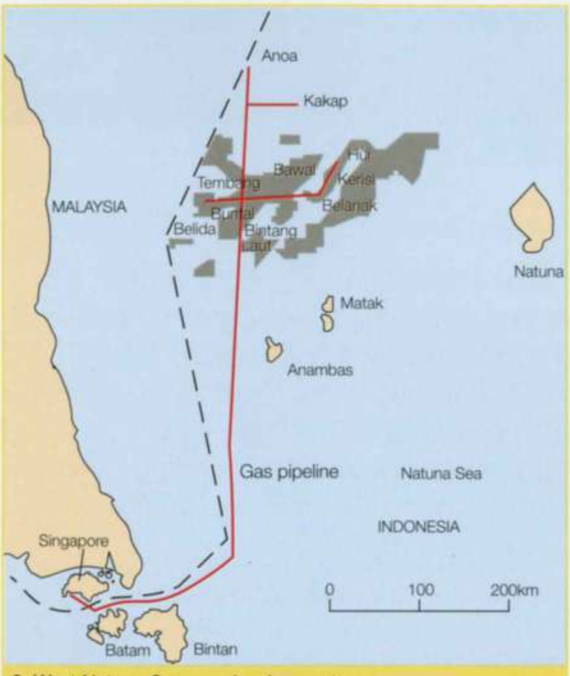
1. Platform ready for wet tow.

Introduction

Conoco Indonesia Inc Ltd's 'Block B' production sharing contract (PSC) lies approximately 1000km north of Jakarta, Indonesia, and 400km north east of Singapore, in the West Natuna Sea (Fig 2). Exploration began here in 1968, and though the initial focus was on finding oil, several natural gas fields in the range 2-8bnm^3 were found. In 1985, efforts began to commercialize this gas. Extensive studies led to the conclusion that the most attractive way to realize its value was through phased development.

Three PSC operators - Conoco, Gulf, and Premier - joined forces to market gas from Block B and the adjacent Blocks A and Kakap. Discussions began in earnest in early 1997, culminating in the April 1999 execution of a gas sales agreement with Singapore. The first step in meeting this commitment was a 500km gas export trunkline from the West Natuna Sea to Jurong Island, Singapore, completed January 2001; the development is now enabling 9Mm^3/day of natural gas to be exported from Indonesia to Singapore.

Conoco's contribution required the production and compression of associated gas from existing facilities at Belida and non-associated gas from new reservoirs over a wide area. As reserves deplete and new fields are brought on stream, compression facilities have to relocate, so an important step was Conoco's selection of Arup Energy's ACE self-installing platform concept[1] to operate as a movable offshore gas production unit (MOgPU), providing flexibility to develop scattered pockets of dry gas across Block B's 1600km^2.



2. West Natuna Sea gas development.

'Arup Energy was appointed to carry out the detailed design of the platform and work with Hyundai in managing the construction and installation.'

The ACE MOgPU, eventually named 'Hang Tuah', combines the benefits of a bottom-founded structure with the ability to move to other areas of the Natuna Sea any time during its 25-year design life. The self-installing concept uses self-contained buoyancy for flotation and a temporary 'on-hire' jacking system to lower the base foundation and elevate the deck (Fig 3).

Phased approach

Phased rather than simultaneous development allows the value and content of the discovered fields to be better understood and is more cost-effective. Early on, Conoco established two important design premises:

- to minimize the fixed platform structures and maximize the movable production and compression systems
- to install facilities at each producing location to deliver quality gas to the export pipeline system, thus using distributed instead of central compression facilities.

As most Block B gas fields contain relatively small reserves, the ability to float over, quickly produce, and then relocate to the next is advantageous and should continue to be so as exploration continues and additional gas discoveries are proven. This approach gives Conoco the flexibility needed to develop these reserves optimally and meet growing natural gas demand in the region.

Concept evaluation

In mid-1997, in parallel with preliminary engineering for the topsides facility, various concepts for the movable compression platform were investigated. These included:

- a new production barge
- conversion of a tanker or other cargo ship
- conversion of a drilling jack-up
- a new small semi-submersible floating production unit
- a fixed platform with a re-useable topsides.

Evolving a new platform design

Fixed substructure development has followed advances in the performance and capacity of installation equipment. With time, structures have become simpler, lighter, and closer to the target of having all their members governed by operational conditions, but these gains were only realized by using the equipment of a small group of specialist contractors who effectively controlled the rate at which the fixed substructure market progressed.

Now, the key substructure development driver is still the method of installation, but solutions that offer savings in both installation and in the more capital-intensive topsides facilities will outstrip those that address installation alone. If these solutions also widen the choice of contractors, or of countries where platforms can be built, further economic benefits may be realized.

Examining operators' new development plans to 2006 shows a similar quantity of hydrocarbons to be won from the traditional fixed platform water depth range of 50-100m as in all developments planned in over 200m of water. This suggests that, although the industry's focus has shifted to deeper water, shallow water developments should not be overlooked in the belief that, as a mature sector, they cannot deliver further innovation.

Traditional platform evolution

Traditional platforms have a piled steel jacket supporting a deck lifted in place by a derrick barge or crane vessel.

Jackets evolved from the earliest Gulf of Mexico piled examples, where the structure supported and surrounded the top-driven piles, forming a jacket. Initially, multiple top-driven piled jackets requiring pile guides were needed in deeper water and harsher environments, but the advent of large capacity underwater hammers made possible the development of jackets without pile guides.

Similarly, high capacity cranes made it possible to lift jackets that formerly could only be installed via launch rails. This elimination of both launch rails and pile guides made jackets cleaner in profile, cut down environmental loading, and led to lower steel tonnage.

Deck evolution followed a similar path to jackets in response to increases in available crane capacity. The heavy-lift semi-submersible crane vessels commissioned in the mid-1980s allowed individual lift weights to approach 12 000 tonnes, thereby eliminating much costly offshore hook-up between the smaller modules constructed hitherto.

However, to lift this weight to the necessary height and reach, the envelope of the 'integrated' deck had to be constrained. The resulting compact, highly integrated decks proved difficult to fit out, particularly when equipment was delivered out of sequence.

This review of traditional platform evolution shows the key drivers to have been the means of supporting the topsides process facilities and installing the platform components offshore. Hence, an analysis of the way platforms could be constructed and installed was likely to pay the greatest dividends when seeking to effect a paradigm shift to more cost-effective concepts.

The evolution of ACE

The development process[3] that led to a range of self-installing platforms began in 1994. By then, Arup Energy was known for designing innovative concrete gravity substructures (CGSs), but had recognized that the total market for them was limited when considering the merits of the substructure in isolation.

Discussions began with several UK topsides designers to explore whether added value could be realized from the combination of large topsides and CGSs.

These designers had observed that the large deck space on floating production storage and offloading facilities (FPSOs) was advantageous in that topsides facilities could be constructed and installed more easily than on integrated decks.

A barge deck was thus proposed that could support topsides facilities similarly to FPSOs and was large enough to easily span between the shafts of a CGS. The idea was developed for the ETAP prospect in the North Sea, but did not gain commercial acceptance at the time.

The following year, Arup Energy was appointed to complete the detailed design of a small hybrid platform, *Q1 Halfweg*, in the Dutch North Sea. The concept - not Arup Energy's - employed a temporary barge, to provide buoyancy to the topsides during installation, and a concrete base.

The experience of installing the *Q1* platform was synthesized with the original barge deck concept into the Arup Concept Elevating (ACE) platform. Its key feature was the permanent barge deck - large enough to support the weight of the legs and base during transportation, and to allow topsides facilities to be economically supported.

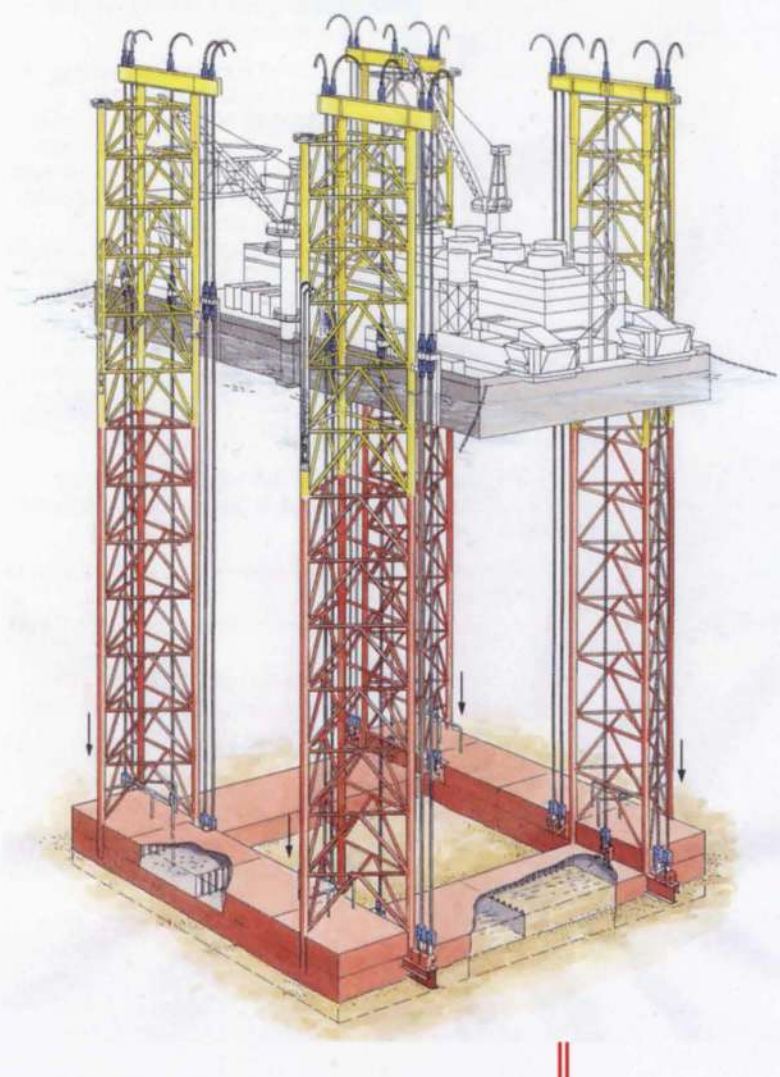
Further economical features were the novel use of a leased strand jacking system for installation and the platform's ease of relocation. The platform concept was developed with a steel gravity or skirted base, depending on prevailing soil conditions.

The ACE concept now extends to a wide range of platform solutions in up to 100m water depth, covering the range from minimal facilities platforms through to large drilling, production, utilities, and quarters platforms.

All offer the benefits of being self-installing, having ample deck space for facilities layout on a single level, and being completely removable or relocatable.

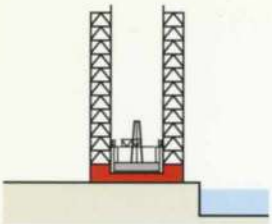
As these benefits become more widely known, an exciting future for this new platform product looks likely.

The Hang Tuah ACE Platform won the much-coveted British Consultants Bureau Innovation Award 2001.

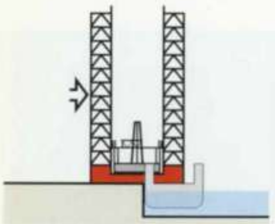


3 right: Artist's impression of an ACE installation.

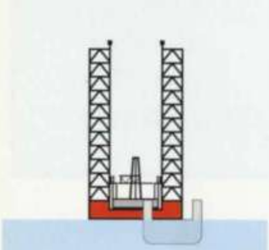
4. ACE construction and installation sequence.



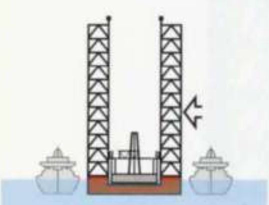
Build and precommission.



Load out.

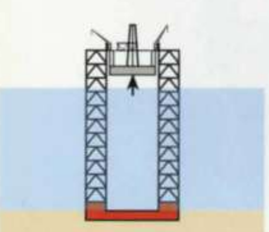


Offload and wet tow to offshore field (can be towed if more economic).



Positition at field using tugs.

Lower legs to seabed.



Raise deck, weld deck to legs, remove strands, commission.

Design basis

Substructure:

- water depth 76-92m (mean sea level)
- first site water depth 82m
- 100-year return period wave height 9.2m
- installation to within 1° of vertical
- positioning to 5m and 5° heading
- long-term settlement not exceeding 600mm
- 300mm differential settlement
- two platform relocations
- limiting sea-state for wet tow: 2.1m Hs
- design life: 25 years
- fatigue life of primary structure: 125 years.

Topsides:

- facility's future operating weight: 4750 tonnes
- 250M standard ft^3/day gas treatment & compression
- provision to store 1000 barrels condensate in deck
- accommodation for 24 persons
- a total of five infield and export risers
- operational deck accelerations not to exceed 0.05g.

At the end of this screening effort, two options were short-listed: a spread-moored barge and a bottom-founded jack-up. Both were technically acceptable and nearly the same cost. The latter was slightly favoured, for reduced motions and the elimination of flexible risers, but the choice of available jack-ups for conversion was limited.

Also, the available deck shape and area for facilities layout of standard three-leg jack-up platforms is not ideal. Both concepts were carried into competitive bidding, and the other three eliminated on cost grounds.

Meanwhile, Arup began a parallel front-end engineering design (FEED) effort in February 1998 to examine the feasibility and merits of adapting its ACE platform to meet the Block B requirements. The original ACE concept was designed for shallower water, but its many advantages were soon recognized, and it appeared to be readily expandable. The deck was increased in size to accommodate the anticipated payload, legs were changed from straight tubular elements to a tubular truss construction similar to deeper water drilling jack-ups, and the base modified to allow for the various soils expected in the Natuna Sea. FEED study results confirmed that a bottom-founded ACE MOgPU in easy-to-build elements could be designed and built within the project time frame.

Selected concept

The ACE platform has several defining characteristics[1]; the attractions that led Conoco to select it as the preferred solution were:

- The rectangular deck configuration was more conducive to process layout requirements.
- A temporary jacking system was cheaper and did not take up valuable space.
- The legs were easier to build without high strength steel.
- Components could be built in various fabrication facilities.

Other characteristics of ACE are that it is:

- self-installing; the barge deck provides the necessary buoyancy during towage from site to site
- based on a packaged equipment philosophy now gaining acceptance as the most appropriate way to develop topsides facilities
- equally applicable as a shallow water, minimum facilities platform or a full drilling / production / utilities and quarters platform
- entirely removable, with minimal environmental impact
- relocatable, making incremental field development or re-use attractive
- and delivers economy and speed of construction through simple, repetitive fabrication details based on shipbuilding technology.

Project execution

The FEED resulted in a two-stage tender process in the second half of 1998 for platform delivery. Six tenderers from Singapore, Indonesia, and Korea submitted bids, each based on a construction and assembly method that suited the particular features of their yards. Conoco awarded the contract to engineer, construct, and install the platform and subsea facilities to the consortium of PT Citra Panji Manunggal (Indonesia) and Hyundai Heavy Industries Co Ltd (Korea) in early 1999. Arup Energy was appointed to carry out the detailed design of the platform and work with Hyundai in managing the construction and installation.

Design

The most important components of an ACE are the:

- facilities
- lattice or tubular legs
- steel gravity base
- barge deck
- jacking system
- installation systems.

Facilities

The main facilities were the twin 15MW centrifugal gas compressors, scrubbers and fin-fan coolers, plus a 24-man accommodation block and main control room at one end of the platform. Facilities were procured on a packaged basis, with emphasis on the use of standard equipment. Smaller units were mounted directly on the deck whilst larger units, like the compressors, are supported on deck framing lines or bulkheads. Circulation routes are provided on the deck and many of the facilities are on a single level – a key aim on an ACE platform. The open facilities layout made blast walls unnecessary.

Future changes are allowed for by providing deck space for anticipated equipment. Such modifications can be either done offshore or the platform returned to shore for major refit.

Barge deck

The 80m x 38m x 6.5m deep deck gives a large uninterrupted rectangular area for the topsides facilities, the layout of which is straightforward because the supporting legs do not protrude into the usable deck space. The internal deck space is largely empty and unserviced. Diesel fuel and potable water are stored in compartments, and a closed drain tank collects run-off from bunded areas. The pipework for this is best located within the deck to avoid having to raise all the facilities above the deck and thus undermining the single-level concept. Though it might seem desirable to make further use of the deck's internal space, this should be avoided as it creates a congested working space that is difficult, and hence costly, to utilize.

During detailed design, the design payload for the deck was increased to 4750 tonnes of facilities to accommodate relocation to future sites, although only 3400 tonnes (dry weight) were initially installed.

Legs

The legs behave as sway-frames in conjunction with the deck and base, and a triangular K-braced structure with a face width of 13m was adopted. The leg size had to be adequate for strength but also with appropriate stiffness to ensure that in-place deck accelerations remained within acceptable limits for a manned facility. Natural periods of 4-5 seconds were predicted depending on the weight / depth combinations considered for the various facilities.

Plain tubular joints without ring stiffening were used. As the jacking facilities were separated from the legs, high local jacking loads were avoided, and steel with a yield strength of 345MPa used. Forged or cast items were unnecessary.

If the platform is relocated to a site deeper than 86m, leg extensions will be fabricated and installed offshore. The 92m depth case generally governed the design of the legs, but the kinematics of the design wave in shallower water led to higher drag loading, so the whole depth range had to be examined to confirm the design.

Permanent supports in the form of I-beams linked the legs to the barge. These connections were deliberately selected to be external to the barge, to minimize their impact on the usable deck space, and to minimize special internal barge stiffening.

Jacking systems

A centre-hole strand jacking system was selected, as commonly used on land for heavy lift operations and load-out. The jacks - similar to those used in civil engineering post-tensioning operations - travel along a cable made of multiple drawn high-tensile strands by alternately locking and releasing grips ('collets'), using hydraulic systems. A hydraulic ram moves a locking plate through which the strands making up a cable can freely pass. At the end of a stroke of the ram, the collets are engaged by mini-jacks to mechanically grip the strands to the plate, allowing the ram to be retracted for the next jacking stroke.

Strand jacks need compressive load to be maintained on the collets so they can only operate in one direction. For this reason, lifting and lowering jacks were required - the former raising the deck in the manner described above. Base descent was controlled by the rate at which hydraulic oil was released from the ram. Pressure control switches prevented the oil discharging too quickly and maintained the hydraulic pressure within prescribed limits.

The key differences between strand jack application on land and offshore are the presence of hydrodynamic load and the need for adequate system integrity during the short offshore installation window.

Hydrodynamic loads are induced in the cables because the base and deck are large enough to be subjected to diffraction forces as waves pass through the platform. As the forces are not necessarily in phase, and since the deck typically experiences an upward load whilst the base experiences a downward load, hydrodynamic loading is induced in the cables. These loads were established by using the linked body feature in the diffraction software, AQWA, with tethers representing the cables. The system was designed for one set of jacks to be inoperable per leg as a contingency measure.

The limiting sea-state for design was an Hs (significant wave height) of 1.0m. It was found that cable loads increased with wave period so swell conditions produced the highest loads. Few data were available on swell in the region but it could undoubtedly be propagated from the north as weather systems crossed these regions.

Cables were run from lifting beams at the tops of the legs to quick-release hooks on the base. Loading in these cables was distributed in proportion to the stiffness of the cable segments above and below the deck, which behave like two springs in parallel. Particular attention must be paid to stages where cable segments are short, as they attract the majority of the load and effects such as relative flexure of the deck, base and lifting beams are much more significant than where cable segments are long.

Several jack configurations were examined before selecting an arrangement with three jacks per cable.

Lifting and lowering jacks were located at deck level and a pretensioning jack at the top of the leg to prevent the cable going slack, a condition that could have caused the collets to fail to re-seat. Three linked computers controlled the jack movements, which could be either force-controlled (all jacks in a group had equal load) or displacement-controlled (all jacks in a group travelled an equal distance). Jacks could also be individually adjusted. In all, 60 jacks were employed, making this the most complex system yet used in an offshore environment.

Steel gravity base

This had to satisfy several design requirements:

- have sufficient area to give adequate foundation bearing capacity
- carry the loads induced in the legs during dry transportation and wet towing
- provide fixity to the leg, thereby lowering the natural sway period of the platform
- cater for a range of soil strengths at the candidate platform locations
- deal with unevenness in the sea floor
- be used to control leg verticality
- be suitable for relocation
- be configured to avoid excessive settlement.

An annular inverted U-section skirted base approximately 60m wide was selected during detailed design as the best foundation to meet these requirements. It proved adaptable to the wide range of sea-bed soil conditions encountered, as well as being more convenient for fabrication and load-out than the alternatives.

The section modulus of the 6m deep skirt was kept as high as possible by thickening the skirt tip with a plate 1m deep and 80mm thick. This large steel area helped compensate for the wide top flange on the inverted U-section. As well as controlling the natural period in sway to acceptably low levels, the selected skirt section had to work as a beam in both transportation and operation.

The requirement to relocate the platform governed the design of the stiffeners to the skirted base. The design catered for an extraction overpressure of 250kPa and a 100kPa suction pressure during installation.

Foundation design

The skirted base was designed to be installed and removed for seven different soil profiles in Block B - generally very soft to soft clays of up to 5m thick overlying stiff overconsolidated clays. The relatively large base area distributed the platform loads widely and thus made a shallow skirt practical (though with its depth rather more than necessary for adequate bearing capacity, to cater for seabed unevenness). Hence, the skirt did not need to penetrate fully.

Settlement control

The foundation was designed to penetrate the relatively stiff clays below the 3-5m of soft surface clays and to carry the vertical load by a combination of end bearing and shear near the skirt tips. The roof of the skirt compartments did not therefore bear on the soft seabed clays that would consolidate under load. Rather, when installed, this space is filled with water at a similar head to sea level, and the platform appears to 'float' on this water cushion.

Installation and removal

The ability to reverse installation is fundamental on a relocatable platform. Whereas the clays contacting the skirts would be remoulded during installation and relatively low suction pressures could be used to assure installation, there would be significant 'set up' during the life of the first field, and a significantly larger underbase pressure would be needed to reverse the process. The pressures were limited by the requirement to maintain a hydraulic seal without losing pressure due to a local blowout or piping.

'ACE, the Arup Concept Elevating platform, now extends to a wide range of platform solutions in up to 100m water depth. An exciting future for this new platform product looks likely.'

5. View up typical leg.

6. Base lowering jacks.

7. Pumping during installation of skirted base.

8. Deck raised to final elevation.

Installation systems

Apart from jacking, the systems needed for platform installation are relatively simple[2]. The annular base was divided into 10 compartments to ensure stability during float-off from the heavy lift transportation vessel.

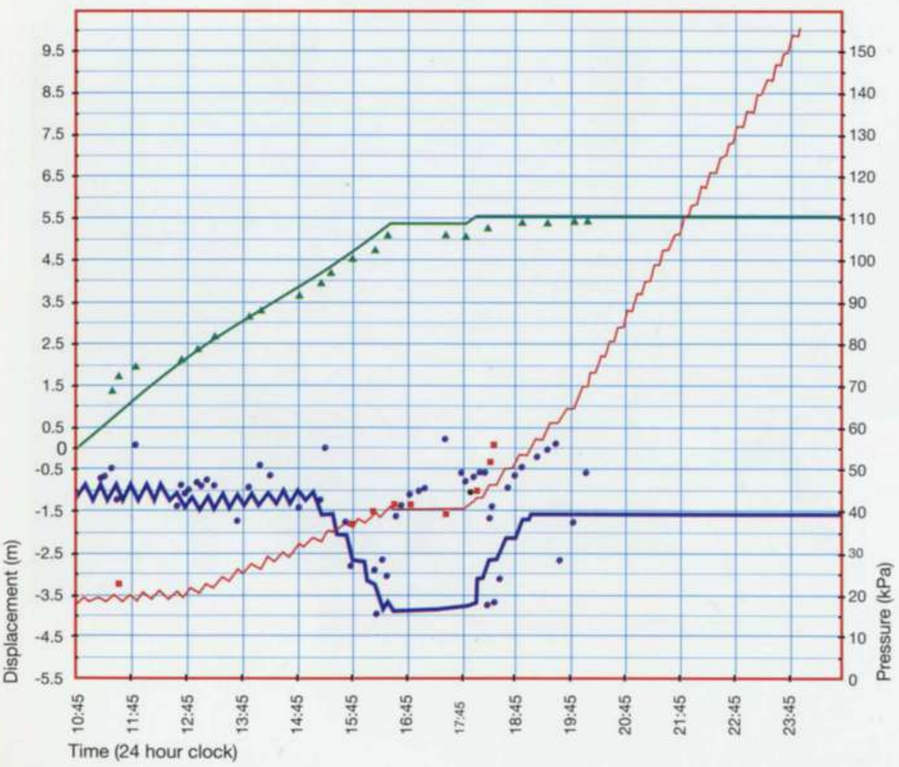
For installation, four equal-sized compartments were formed in the base by opening valves to link the sub-divided compartments after float-off.

A network of pipes led back to a penetration in each leg's outer chord, which was used as a caisson containing an submersible electrical pump set: a tandem arrangement to give some contingency for equipment failure during installation. The pumps discharged to the sea through a penetration high enough in the chord to cater for subsequent platform relocation to a deeper site. Close to each pump were two pressure gauges, one in the caisson and one outside. The pressure difference between the two was of key importance to the installation and foundation design and had to be continuously monitored during skirt penetration. The load applied to the skirts after touchdown depends on:

- the strength of the foundation soils
- development of a hydraulic seal in each compartment
- deck draught
- pressure applied in the skirt compartments
- the tide whilst the deck is in the water.

The skirt loading and resultant penetration are varied and controlled by the rate at which water could be pumped from the skirts, and the rate of jacking. Excessive overpressure in the skirts could have led to loss of the hydraulic seal, and excessive use of suction pressure could have made the platform difficult to relocate.

The bathymetric profile available during design was not detailed enough to show any local depressions liable to affect the ability to form the hydraulic seal, so the consequences had to be evaluated. The skirt was relatively flexible, yet needed to stay planar during installation and subsequent operation. This necessitated careful hydraulic control of each compartment during skirt penetration, a condition introduced by the selection of the skirted base.



9. Predictions and measurements for installation.

The strong inter-relationship between the variables and the effect they had on skirt penetration loads necessitated extensive modelling with a specially written finite difference program. The effects of different soil strengths, pumping rates, jacking rates, and tidal variation were studied to minimize the possibility of unforeseen circumstances arising on installation. Fig 9 shows how output from the prediction program closely matches the actual installation sequence.

Construction

Fabrication commenced in March 2000 in Hyundai's Ulsan yard, Korea. The 9150 tonne platform was assembled on the quayside from block sub-assemblies fabricated in covered shops, the entire structure being completed in 11 months.

The inverted U-section skirt proved straightforward to fabricate using plate-line techniques, and the straight sides and substantial section of the skirt enabled conventional skidded load-out.

Facilities erection took from September 2000 to March 2001; the major elements were the long-lead compressors. The jacking subcontractor, PSC Heavy Lift Ltd, commenced installation of the equipment in February 2001 and was ready for a trial lift sequence and onshore commissioning by early March.

Marine operations

The platform was loaded out onto Dockwise's heavy transport vessel *Transshelf* in late March 2001, ready for departure on 31 March. After the seven-day voyage to the offloading location in the sheltered waters of the Anambas islands in the Natuna Sea, the platform was held whilst infield pipelaying by Hyundai's HD-423 installation support vessel was completed.

At this time the jacking system was activated to equalize the loads in the jacks now that the platform was supported from the deck rather than from the skirt tips. A clamping force was also applied to keep the base in contact with the deck during the wet tow. Two 100 tonne bollard pull tugs towed the platform 60 nautical miles to its final installation site in 82m of water near the Tembang Field. Here conditions were not immediately favourable, with seas of over 1m, and installation finally commenced on 18 April 2001.

Installation

Following an improving forecast, installation was completed in 54 hours, compared to the expected 42 hours. First, buoyancy boxes were flooded above the skirt compartments, and then base lowering began. The anticipated 5m / hour in fact averaged nearer 3m / hour.

Lowering paused with the base 1.5m from the seabed, and the pumping system was activated and function-checked. For touchdown and initial skirt penetration, the jacking system was switched to a dual mode of operation, in which the load is shared between the lifting and lowering jacks. As skirt penetration proceeds and load is gradually released from the lowering jacks, the lifting jacks become more dominant. Eventually, the lowering jacks travel freely along the strand without picking up load, and from here on only the lifting jacks are used.

Skirt penetration depends on the volume of water discharged by the pumps. Head differentials were monitored and maintained within the design limits by turning individual pumps on and off. This dictated when the jacks could next be operated. Skirt penetration took eight hours, including 1.5 hours for the compartment pump test, and concerns previously expressed about the difficulty in achieving a hydraulic seal in the soft surface silts proved unfounded.

With penetration complete, deck raising continued to its weld-out elevation, which was achieved late on 20 April 2001. The leg verticality achieved was well within the 1° tolerance, with angles of 0.17° and 0.34° achieved respectively in the longitudinal and transverse directions. The planarity of the base was also within acceptable limits. Deck connection weld-out and jacking system removal were completed two weeks after installation. Facilities hook-up and commissioning proceeded in parallel, and Hang Tuah was brought into operation on 26 June 2001.

10. Hang Tuah in operation.

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(2) JACKSON, G, *and* PENNINGTON, DS. Installation of the Hang Tuah ACE Platform, Eighth International Jack-up Conference, London, September 2001.

(3) JACKSON, G, *et al* OTC12970, Development of economic self-installing steel gravity platforms, Offshore Technology Conference. Houston, Texas, May 2001.

Credits

Promoter:
Pertamina

Operator:
Conoco Indonesia Inc. Ltd (Inpex and Texaco: Conoco's partners in PSC) (Premier and Gulf: Partners in West Natuna Sea Development)

Main contractor:
Hyundai Heavy Industries Co Ltd, with PT Citra Panji Manunggal

Dry transportation contractor:
Dockwise bv

Jacking contractor:
PSC Heavy Lift Ltd

Topsides concept design:
Enercon Inc

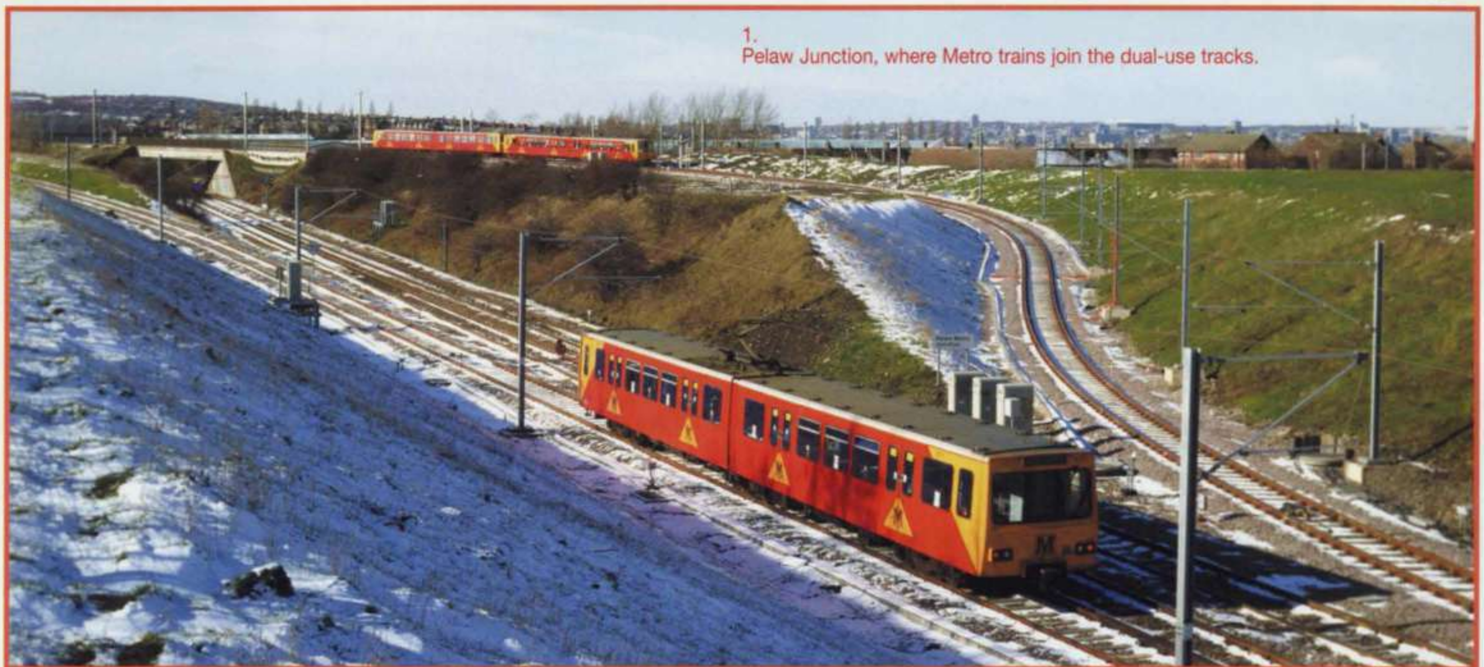
Subsea facilities design:
JP Kenny Pty Ltd

Marine warranty surveyor:
Global Maritime

Platform designer:
Arup Tunde Ajala, Randi Andersen, Robert Blair, Craig Braynion, Vicki Buckley, Christopher Cann, Paul Cassidy, Andrew Cunningham, Pali De Silva, Adrian Fox, Andrew Godfrey, Ian Goldsmith, David Gration, Haryanto, Kubilay Hicyilmaz, Gordon Jackson, Mevin Kistnassamy, Richard Kollek, James Lawton, Bob Lea, Jerome Legendre, Andrew McNulty, Sri Nadarajah, Rhonda Nicoll, Andy North, David Palmer, Bernie Pemberton, Richard Purdy, Brian Raine, Phil Rawstron, Rupert Rowland, Richard Seago, Brian Simpson, Rob Smith, Bruce Stowell, Graeme Taylor, Faye Tiernan, Ksenija Vucinic, Ben Watkins, Jason Yeomans, Alexey Zavgorodniy

Illustrations:
1, 5-8: Gordon Jackson
2, 9: Daniel Blackhall
3: Fred English
4: Penny Rees
10: Conoco

Sunderland Direct: facilitating a railway



1.
Pelaw Junction, where Metro trains join the dual-use tracks.

Martin Butterworth Nick Fennell Neville Long Graeme Mellor Colin Stewart

Introduction

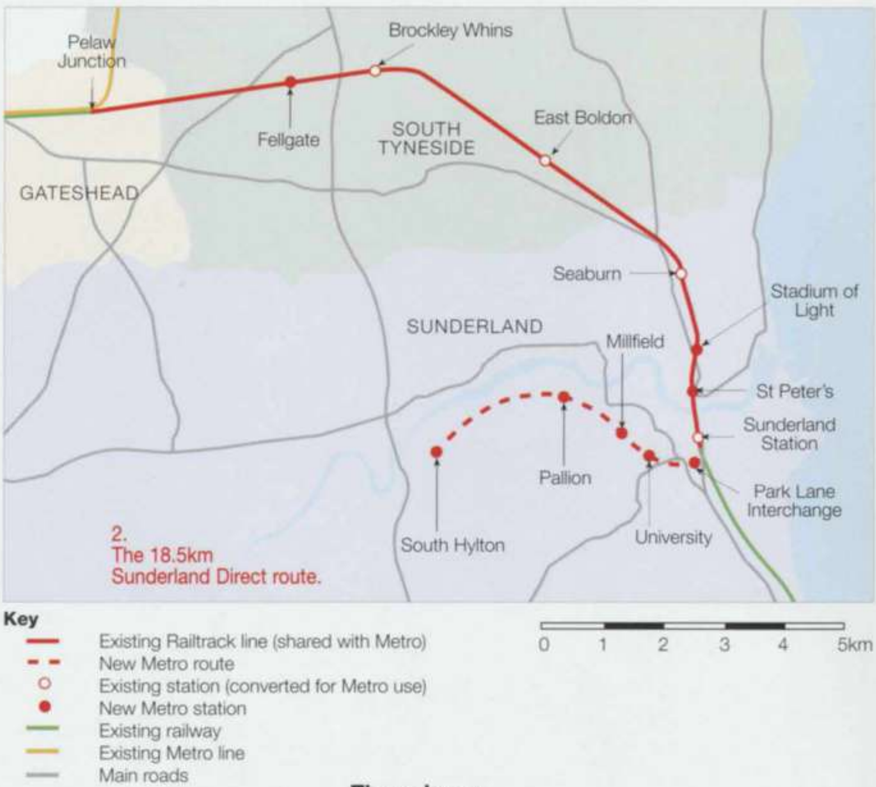
The UK's new era of urban light rail transport was ushered in when the first phase of the Tyne and Wear Metro system opened around Newcastle upon Tyne and Gateshead in 1980-84. Its success clearly pointed towards the system being extended, notably south-east to the then newly-created city of Sunderland; now, some 10 years after the start of planning, 'Sunderland Direct' continues the Tyne and Wear Metro through the centre of Sunderland and on to the suburb of South Hylton (Fig 2). This is an innovative rail solution to urban transport congestion in that, for the first time in the UK, light rail and heavy rail passenger and freight trains share existing track. This 13.5km section runs between Pelaw in Gateshead and Sunderland city centre. Then the new section of the Metro diverges to follow part of the disused former Sunderland-Durham rail route (latterly the Pallion branch) to South Hylton (5km).

Initial studies in the early 1990s showed that traffic volumes between Newcastle and Sunderland and low car ownership justified a major upgrade to the transport system.

Arup involvement began in 1994 with the preparation for Nexus, the Tyne and Wear Passenger Executive which runs the Metro, of an Environmental Impact Statement on the proposed scheme. This commission lasted five years and included scheme designs for both new and existing stations. Arup was also involved in the Public Enquiry in January 1998, preparing proofs of evidence and and providing expert witnesses on behalf of the project.

In October 1998 the Department of Transport announced that the project would be a public-private partnership between Nexus and Railtrack, the UK rail infrastructure operator. The Public Inquiry Inspector granted planning permission, and government approved the final proposal in December 1999. The total project value was £150M, funded by Railtrack, Nexus, central government, and the European Regional Development Fund. Railtrack led the design and construction of the system and took responsibility for the infrastructure, with Nexus becoming a train operating company over the route and station facility owner for the new stations.

Railtrack established an alliance with leading industry suppliers in February 2000 to design and build Sunderland Direct. Work began on site in March 2000 and the passenger service started on 31 March 2002. Up to 10M people per annum are expected to use the new system, bringing many socio-economic benefits for the whole region.



2.
The 18.5km Sunderland Direct route.

The scheme

Sunderland Direct broadly comprises the following components:

Permanent way: two new junctions at Pelaw and Sunderland, track re-alignment / lowering, and new permanent way between Sunderland and South Hylton

Civil engineering: earthworks, major service diversions, modifications to bridges, subways and culverts, various retaining wall structures, new bridges and cycleways

Stations: eight new including two sub-surface, one of which forms a major interchange with the bus network, and rebuilding of four existing

Electrification: 1500V DC system including three new substations

Signalling: a new system to give paths for six Metro trains per hour in each direction, stopping at all stations, three heavy rail passenger trains per hour in each direction (only stopping at Sunderland and Heworth), and one freight train per hour in each direction. The design includes measures to keep heavy and light rail trains apart using TPWS and Indusi train stops at each signal for the heavy and light rail train respectively. Control of the new system is from the main Tyneside Integrated Electronic Control Centre (IECC).

Remote control: Supervisory Control and Data Acquisition (SCADA) equipment and associated telecommunications services, for control of the Sunderland extension electrification system. Electrical management of the whole route is controlled from the regional centre in Doncaster.

Telecommunications transmission: two new fibre optic communication networks have been installed: one links the signalling functions and the other is an extension to the existing Metro OTN 600 communication system to link the retail telecom functions.

Procurement and project participants

In 1999 Railtrack appointed Arup to assist with preparing documents for the design-and-construct tenders for the new Sunderland-South Hylton line.

This commission was extended to Arup helping to assess tenders through to award. For the major modifications to the existing Sunderland-Pelaw Junction line, Railtrack formed a partnership with existing zonal infrastructure contractors, whilst for the Sunderland-South Hylton line they established the 'Sunderland Direct Alliance' (Fig 3). This was also responsible for designing and installing the 1500V DC electrification and the new project-wide signalling system, and constructing the new Pelaw Junction.

Arup was appointed as planning supervisor and co-ordination facilitator to identify and enable the resolution of all design and implementation issues associated with Sunderland Direct. This role developed significantly, due largely to the demands of the programme and various events during design and construction, eg the initial main civils contractor going into administration.

This necessitated a much more 'hands on' approach to assist with and facilitate the production of information by Alliance contractors. Over 50 Arup staff contributed significantly to this commission over a period of two years.

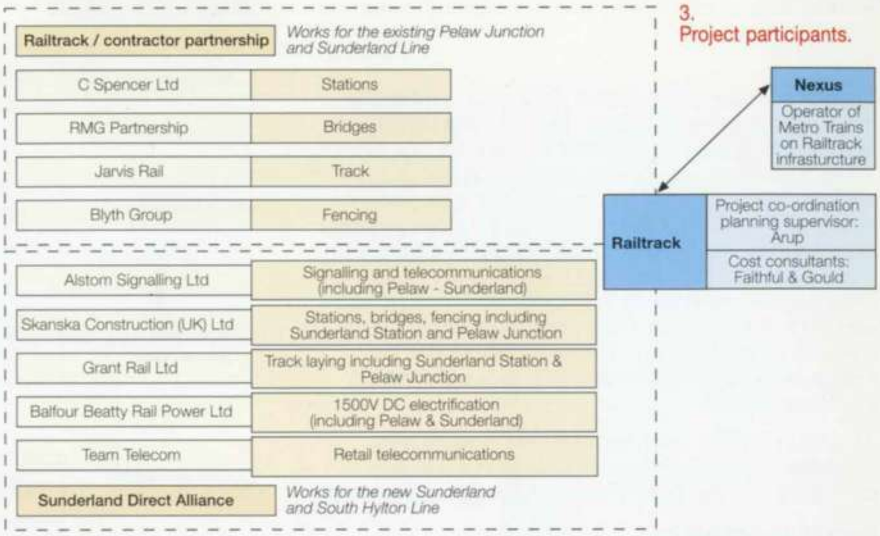
Arup played a major role in developing the Alliance, facilitating meetings to develop relationships and define the Alliance Charter and mission statements, etc. Arup became an integral part of Railtrack's project management team, facilitating numerous meetings such as value engineering forums on all aspects of the project. Several principal contractors were appointed, giving interesting management interface issues that required review and revision as the project progressed. Arup, as planning supervisor, developed a 'principal contractor strategy' to address these.

Though this article concentrates on Arup's co-ordinating role in Sunderland Direct, it must be emphasised that the project's success, delivered on time in less than two years, is testimony to the excellent teamwork that existed between all participants, and to the expertise within Railtrack as client.

Technical and statutory approvals

General approvals

Arup was responsible for co-ordinating all technical and statutory approvals on Sunderland Direct (over 250 separate applications to the three local planning authorities), and appointed local architect Reid Jubb Brown Partnership to process these. An Environmental Liaison Group (ELG) for each of the three areas (Gateshead, South Tyneside, and Sunderland) was set up, including representatives of the operator, contractor, affected residents, and the relevant authority. Arup convened these ELG meetings, which reviewed issues or complaints, identified priorities for processing consents, outlined future construction works, and agreed actions to mitigate impacts and minimise disruption. Arup Acoustics helped develop the most efficient process for discharging the planning conditions on noise and vibration, and audited contractors' performance (Fig 4).



3. Project participants.

The firm also liaised with utility companies, co-ordinating the design and implementation of works required to their assets, and co-ordinated the various temporary and permanent road closures needed to implement the works, ensuring maximum benefit from each closure.

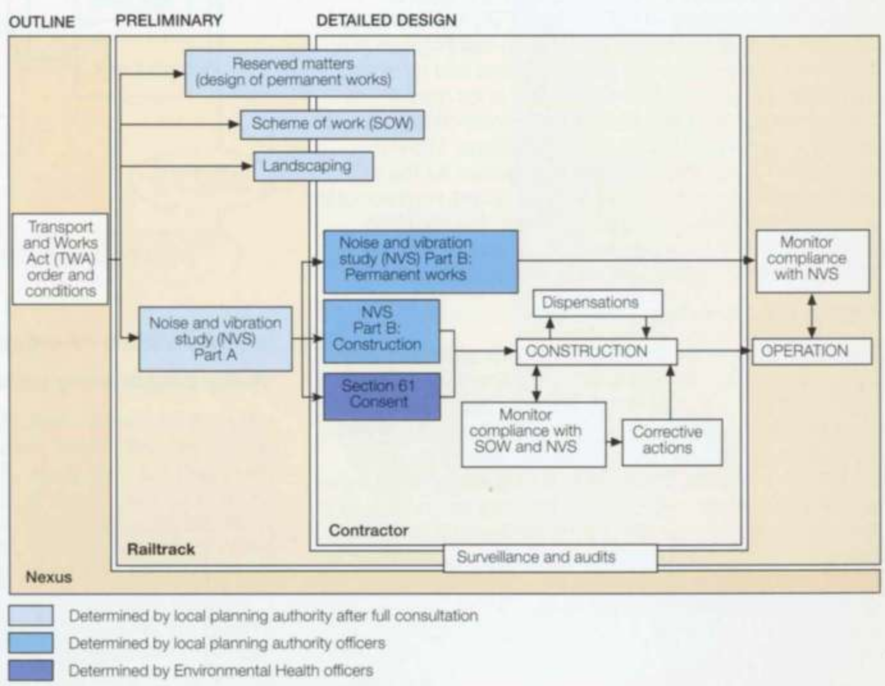
Railway-specific approvals

Arup implemented Railtrack's design review process in relation to new civil engineering infrastructure and the stations between Sunderland and South Hylton, reporting to the Railtrack project manager and liaising with their lead design and construction engineer to ensure that appropriate engineering standards were used. In the UK, new or modified railway works - including trains, locomotives, and coaching stock/wagons - require various types of approval from Her Majesty's Railway Inspectorate (HMRI) (see Fig 5).

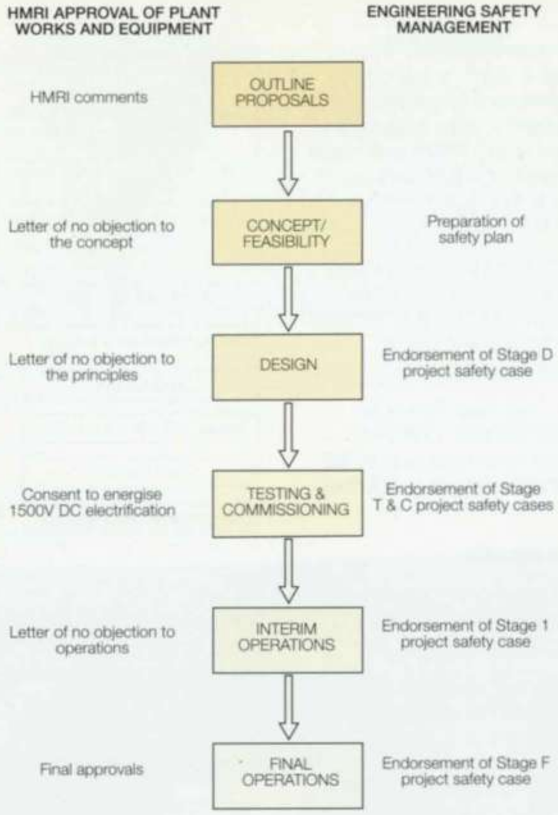
Throughout the design period and beyond, regular monthly liaison meetings were held, with HMRI's New Works Inspector in attendance. These gave the design teams access to the Inspectorate for advice, guidance, and interpretation of the requirements, and meant that the New Works Inspector had first-hand knowledge of the developing design and construction. Arup's project HMRI co-ordinator chaired and managed the liaison meetings, and was the initial point of contact between HMRI and the project teams, including Railtrack and NEXUS. He also prepared and issued the required certificates and supporting documents and accompanied the Inspecting Officers on pre-inspection walkouts and formal inspections.

Sunderland Direct won 'Major Project of the Year (Civil)' at the 2002 National Rail Awards.

4 below: Agreed process for discharging noise and vibration conditions to the Tyne & Wear Passenger Transport (Sunderland) Order 1998.



5 right:
HMRI approval and engineering safety management stages.



Engineering Safety Management (ESM) is the process for managing the safety of changes that may affect railway safety, primarily before the change is made, and the Project Safety Case is the way this process is presented. It sets out the safety justification for the proposed change to the railway, and is updated and modified as the project matures to completion (Fig 5). On completion of the change to the railway, the residual hazards and the permanent control measures are then incorporated into the railway infrastructure operator's Railway Safety Case. Arup provided the Safety Case Manager specifically to manage and oversee the ESM work of the project team and to work with Railtrack and Nexus officers.

Arup also provided a member of staff to manage and co-ordinate the liaison between contractors / suppliers and Railtrack Acceptance Services for product acceptance.

Design co-ordination

Facilitation

Railtrack's procurement strategy had arranged for seven different contractors and their respective designers to be involved in the overall design. Arup facilitated co-ordination between them, initially holding co-ordination meetings for both the existing and the new line to enable design principles to be developed and agreed. As the design developed, the emphasis of the meetings changed to resolving specific technical problems and a formal interdisciplinary sign-off by each of the contractors on each other's drawings.

The design / construction interface was critical to this fast-track project. Arup monitored this and facilitated meetings to resolve conflicts and decide the best way forward for the project as a whole.

Station systems

All the stations are highly-serviced facilities, equipped with CCTV, ticket machines, passenger help points, passenger information displays, PA and, where appropriate, fire alarms, lifts and escalators. These systems were designed to be remotely monitored from the Metro Control Centre at South Gosforth. Arup developed a set of system integration diagrams to define interfaces between contractors (Fig 6); at each interface a specification and protocol was agreed.

Railway control systems integration

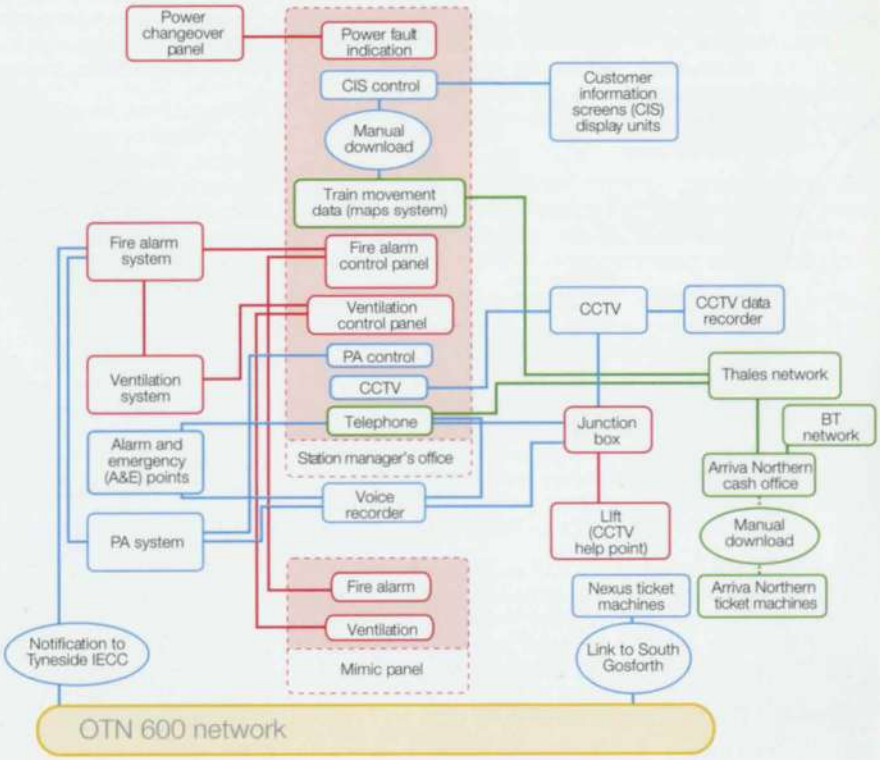
HMRI required trains to move seamlessly over the infrastructure boundary from Metro to Railtrack control with no action needed by drivers.

Arup, under a separate commission with Alstom, the signalling and telecommunication contractor, used its railway control system integration capability to ensure this was delivered. The Metro's Positive Train Identification (PTI) system for automatic route-setting of trains and for driving the passenger displays on stations had to be modified to communicate with Railtrack's automatic route-setting system and to drive the displays on the new stations. The PTI system also drives the automatic changeover for the cab secure radio system to ensure that the drivers communicate with the correct infrastructure controllers. Arup worked closely with the PTI system suppliers to ensure that the interfaces were properly specified and operated correctly.

Earthing and bonding

The rails themselves demonstrate the interdependence of disciplines. As well as supporting the trains, they provide the traction current return path and carry the track circuits that input to the signalling system. With the DC traction system, particular attention had to be placed on the earthing and bonding to ensure that accessible and touch potentials were within defined limits and that stray currents were controlled. Arup facilitated co-ordination of the earthing and bonding plans for the route, bringing together the signalling and overhead line designers and those that had to bond structures to the rails along the route.

6.
Sunderland Station: system integration design.



Implementation co-ordination

Master programming and interdisciplinary planning

Initially, Arup assisted Railtrack with preparing a co-ordinated design and construction master programme; Railtrack developed this base document during the project to plan future work and monitor progress. The site was constrained by limited access points and restrictions on working hours, which for the new line being built through residential Sunderland were restricted to normal daytime hours. Conversely on the existing line, the train service continuing through the project forced contractors to work during the eight-hour train-free period. Again, Arup facilitated regular co-ordination meetings to bring the contractors together to plan works and resolve any conflicts.

Major possession management

A limited number of extended closure periods, when trains were suspended or disrupted, were required for some of the works. Each had to be planned well in advance so that passengers and other rail users could be kept informed and the maximum possible work be achieved within the period. Any overrun would both disrupt the public and incur financial penalties for the project and its contractors. Arup facilitated co-ordination meetings to ensure efficient management of these possessions and produced management documents to allow monitoring during them.

The most significant major possession was a six-week closure of the Newcastle to Sunderland line in early spring 2001. During this period the existing track through the Sunderland North Tunnel was lowered and two new crossovers introduced, the platform within Sunderland Station was widened, and the new junction and track arrangement south of the station was introduced and commissioned. The station was kept open to passengers throughout to allow trains to run south to Middlesbrough.

Commission planning

Signalling and overhead line system

Nexus signalling was modified to allow the new Pelaw Junction to be controlled and to accept Railtrack signalling inputs. The Railtrack infrastructure was completely re-signalled and control was transferred from the existing four signal boxes to the main box at Tyneside.

Alterations to the Nexus signalling were done in advance over two successive weekends, during the second of which services over much of the existing Metro system had to be halted while the new control panel was installed and the full system tested.

The Railtrack signalling was commissioned in January 2002, with the existing line closed for two weeks to enable the changeover. The overhead line commissioning was integrated into this period to make maximum use of the shutdown. In the first few days the old signals had to be taken down, other redundant equipment removed, and the bonding changed over so that the overhead electrification could be safely switched on. By the end of the first week the equipment was successfully changed over and ready for testing, but before this the new signalling control desk in the IECC had to be brought into use. This necessitated a complete six-hour shut-down of the area controlled by the IECC, from North Yorkshire to Northumberland and including the East Coast main line. When the new desk was commissioned, correspondence testing had to be completed before two test trains (one for signal sighting and one for proving the signalling system) could be brought in and the new signalling signed back into use. In the run-up to these commissioning periods Arup worked closely with Railtrack and Nexus. Method statements and programmes were prepared and agreed, and procurement of materials, installation, and pre-testing were all monitored and reviewed regularly.

8.
Park Lane Interchange.

During the actual commissioning Arup was involved with monitoring the milestones and managing any issues that arose. Informing both the general public and railway staff that the new line was now electrified required a major information campaign. Formal notices were placed in numerous depots, offices, etc. Railtrack undertook an awareness campaign with local schools along the route.

Station systems

All station functions had to be fully tested before public opening. A logical sequence was developed to ensure that all the systems on each station demonstrably functioned together, and that all the stations could be controlled from South Gosforth. The first stage in this was to define the entry criteria covering such items as physical works, evacuation routes, and the station systems; when all these had been signed off individually, combined testing could proceed. All aspects of each station's functioning were covered, and the functioning of the controlling network gradually built up and monitored as each station was brought on line.

9.
Tyneside Integrated Electronic Control Centre (IECC).

10.
New highway retaining structure and rail infrastructure at European Way, adjacent to Pallion Station.

7.
East Boldon Station: Metro train alongside heavy rail (Arriva) train on dual-use line.

Dynamic testing or running test trains

Planning

To verify the effects of the infrastructure on trains and vice versa, a series of tests using a Metro car were proposed. These included a proving run doing gauging checks and pantograph monitoring, followed by tests at increasing speed, proving emergency train stop and overspeed systems, radio coverage, signal sighting checks, and electrical and telecommunications performance. Serco Railtest Ltd was brought in to operate the train and provide the testing safety case, track access agreement, and train operator licence needed to conduct these types of test. Arup provided the link between Serco and the Alliance contractors to enable the detailed testing proposals to be developed. Once the proposals became clear, the testing programme and methodology were developed to enable the safety case to be produced and authority sought from HMRI to conduct tests.

Arup managed the testing programme, ensuring that all appropriate possessions were taken, signal box instructions were available, and - where appropriate - authority was granted to exceed line speed.

Test train running

Tuesday 29 January 2002 saw a significant milestone, when the first Metro train was brought across the boundary and successfully taken 'at caution' all the way from Pelaw to South Hylton, with Arup staff on board completing the gauging checks which enabled subsequent runs to be faster. The test train was a conventional Metro car, but with a specially adapted pantograph fully gauged up with roof-mounted video monitoring equipment. A conventional Railtrack overhead line monitoring train could not be used since the power supply voltage is different.

Over the following few days an intensive test programme was completed, making the route available for driver training by Sunday 3 February with only minor restrictions, gradually removed in the next few weeks.

Railway operations

Operations planning

A joint operations group was established to manage the operations issues arising from the introduction of Metro services onto Railtrack infrastructure. This covered such items as cab-secure radio protocols, speed signage, recovery strategies for failed Metro trains, emergency planning, and managing of the infrastructure boundaries. The operations sides of Railtrack and Nexus were brought together in a forum to address issues arising from the development of the operational safety cases and vehicle acceptance processes. Arup provided the secretary for this group, and linked with the construction project.

Trial running / driver training

Throughout February and March 2002, heavy rail trains were suspended at weekends to allow for Metro driver training. These runs provided essential feedback on the operation of the overall system and allowed issues to be investigated and resolved before passenger services started.

Arup was involved in gathering feedback and managing issue resolution with the various contractors.

Transfer into maintenance

From early in the project Arup worked to involve Railtrack's Zone Asset Stewards, who manage the day-to-day operation of Railtrack Assets, and the maintenance contractor in the design process. They were able to give the benefit of their experiences and feel they had a hand in shaping the systems for which they would be responsible. This approach eased the process of acceptance of the assets into maintenance once they were complete and commissioned.

11. Pallion Station.

Throughout the project train services were maintained along the existing section of the route. This meant the continuation of routine maintenance in parallel with construction work. The needs of both sides had to be understood to balance their requirements. For example, track maintenance tamping had to be discontinued for an extended period to enable the overhead line to be fully registered.

To achieve the transfer of project assets into maintenance, the spares required had to be identified, staff trained, documentation completed, and a joint inspection carried out. Due to the short timescales, both training and spares could only be provided as the works were completed; documentation required included O&M manuals, the Health & Safety file, and data to be input into the various Railtrack databases. Arup handled the control, co-ordination and ultimate circulation of the documents, and the collation, checking and submission of database input from the various contractors to the Railtrack Zone Data Manager. The firm also arranged for joint inspections to agree any outstanding works to be completed before maintenance could be transferred. These inspections also gave the Asset Steward and maintainer the opportunity to have a detailed look at the works with a view to planning their maintenance programmes - a process that is ongoing at the time of writing.

Future maintenance

Throughout the project Arup liaised closely - through more workshop meetings - with the local authorities, Railtrack, and Nexus regarding the assignment and transfer of assets created by the project. The mechanism for legally transferring assets is currently being drafted and will be implemented in the near future.

Conclusions

Sunderland Direct has been an extremely complex project, combining all aspects of engineering, innovative solutions, major interdisciplinary issues, and works on live railway. Though it passes through Sunderland city centre and suburban areas, it was constructed with minimum disruption to residents in less than two years. This was a remarkable achievement, given that it involved 12 new / rebuilt stations - two of them subsurface - total signalling replacement and traction power supply and telecommunication systems, all integrated into the Railtrack and Nexus control centres.

Future potential

If this new venture of joint running of light and heavy rail trains proves successful, it will no doubt demonstrate an option for future schemes.

Credits

Promoter:
Nexus (The Tyne & Wear Passenger Executive)

Client:
Railtrack plc (In Railway Administration)

Project facilitator and planning supervisor:
Arup Robin Anderson, Ian Bambrick, Lesley Banks, Simon Binks, Daniel Blackhall, Martin Butterworth, Andrew Carr, David Charters, Kirsten Crowther, Alan Dunlop, Nick Fennell, Peter Gibson, Andrew Goodfellow, Richard Greer, Mike Hall, Simon Harris, Shaun Hartley, Rob Hartshorne, Tim Holland, John House, David Hughes, Neville Long, Adrian Lowe, Chris Manning, Juan Martin, Sean McDermott, Graeme Mellor, Charles Milloy, Claire Noble, Jeremy Palmer, David Peck, Chris Platt, Keith Prentice, Kulvinder Rayat, Steven Reay, Penny Rees, Colin Robertson, Colin Robinson, Mark Rudrum, Jane Saul, Peter Scott, Stuart Stephen, Phil Stephenson, Colin Stewart, Dave Swainson, Gordon Thompson, Chris van Lottum, Tony Vidago, Jo Webb, Eric Wilde, Andy Woodland

Sub-consultant architect (planning and environmental co-ordination):
Reid Jubb Brown

Contractors:
C Spencer Ltd
RMG Partnership
Jarvis Rail
Blyth Group
Alstom Signalling Ltd
Skanska Construction (UK) Ltd
Grant Rail Ltd
Balfour Beatty
Rail Power Ltd
Team Telecom

Acknowledgements:
Neil Simmons, Railtrack plc (In Railway Administration)
Kieran Dunkin, Railtrack plc (In Railway Administration)

Illustrations:
1, 10: © Sally-Ann Norman
2-6: Claire Noble
7-9, 11: Penny Rees

The Utah Oval: Olympics and legacy

Leo Argiris
Ignacio Barandiaran
Nigel Tonks
Steve Walker

1. The arena in use.

Introduction

Men's long-track speedskating has been part of the Olympics since the first Winter Games in Chamonix, France, in 1924. Women's events were added in 1960. In both, two skaters race against the clock on a 400m oval. Today's competitors hone their skills to exacting tolerances in a sport measured by hundredths of a second. In a speedskating oval, baseline variations of fractions of an inch and minute inconsistencies in ice temperature make the difference between ordinary races and record-setting performances.

When the Salt Lake Organizing Committee (SLOC) for the 2002 Winter Olympics selected its speedskating site, it chose the highest altitude of any indoor skating oval in the world - 4675ft (1425m) in Kearns, Utah, 14 miles (22km) southwest of downtown Salt Lake City, USA. Thin air is less resistant to skaters, whilst the dense, hard ice of high altitudes gives faster times. The challenge for the Utah Oval's design team was to capitalize on the site's elevation to create the fastest sheet of ice in the world.

Brief

Salt Lake City-based Gillies Stransky Brems Smith Architects (GSBS) and Arup worked with SLOC to set objectives for the building:

(1) Craft the fastest possible ice

SLOC staff included former Olympians focused on catering for athletes and producing optimal ice conditions.

(2) Create a bright, pleasant indoor training environment

The facility had to be practical for post-Olympic 'legacy' use for year-round training by the US Olympic Speedskating Team. GSBS strove for a welcoming facility for recreational users that would ultimately promote the sport.

(3) Set an example of energy efficiency

Shortly before Salt Lake City won its bid to host the Games, the International Olympic Committee added 'Environment' as a third pillar of the Olympic movement along with 'Sport' and 'Culture'.

(4) Accomplish this within a limited budget

In the project's formative days, the design team helped SLOC determine whether it could afford a permanent indoor Oval. SLOC also faced substantial one-time costs associated with hosting Olympic events; the permanent facility had to accommodate temporary power, parking, media tents and broadcast facilities, and each of these had to be carefully co-ordinated with SLOC's venue-planning staff for minimal cost impact.

The speedskating facility for 1998 Olympic Winter Games in Nagano, Japan, cost nearly $300M. Even allowing for Nagano's 50% larger seating capacity and substantial construction cost differences between the USA and Japan, SLOC knew that it would be a challenge to meet its objectives with a budget totalling about $27M.

(5) Complete the facility a year before the Olympic Games

SLOC needed time to commission the systems, resolve the snag list, familiarize operations staff with their equipment, and allow the US Olympic team to train in advance of other international athletes.

All these objectives pointed to a utilitarian structure. However, the designers used this practical outline not as a constraint but as a springboard to give the 2002 Winter Games a signature building. Ultimately, it needed to be inspirational for the athletes as well as the community.

'The Utah Olympic Oval is now a thriving recreation facility in the Salt Lake Valley with a busy schedule of ice hockey matches and speed skating competitions.

It is also the year-round training facility for the US speedskating team.'

Team

GSBS appointed Arup for full building and acoustic engineering to scheme design, with structural and mechanical disciplines extending through design development, and Arup and GSBS assembled a project team in spring 1998. GSBS's experience in designing sports facilities and sustainable / low-energy design complemented Arup's experience in sustainable and long-span structures. Very few firms around the world have experience with this specific building type. However, Arup's 'first principles' approach to design, its global experience base, and the advanced design tools at its disposal earned the client's confidence and the commission. The firm was responsible for scheme design of the structure and building services, and detailed design of the arena roof structure. Several Salt Lake City-based engineering consultants completed construction documents (except for the roof structure) and performed the bulk of construction administration tasks supporting the GSBS / Arup team. Sterling Engineering of Calgary was appointed to design the ice slabs and Van Boerum & Frank the refrigeration system.

The project was developed in three phases:

- Feasibility and concept design (May-August 1998)
- Final design (scheme design through construction documents, November 1998 - June 1999)
- Construction (August 1999 - February 2001).

Concept

The client, design team, and cost consultant gathered in Salt Lake City for a series of design brainstorming sessions. It was clear from the start that the right roof was key to success, and first the team focused on what that roof would enclose. In the conceptual interior layout that emerged, the spectators were accommodated on three sides of the arena to maximize athletes' experience of a cheering crowd, but minimize the span. Sightlines were studied to determine optimum distances and heights from the stands to the track, with disabled access requirements, a jogging track, media photographers, the rail-cam, and judging and broadcasting platforms all taken into account.

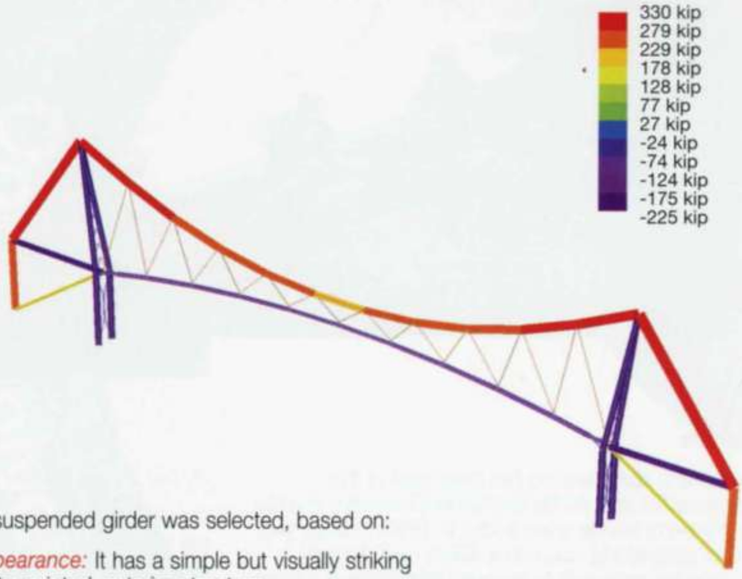
The client's design criteria embraced:

- an indoor arena on the site of an existing outdoor oval, housing the 400m Olympic oval, two regulation-sized ice hockey sheets in the centre of the speedskating track, and 6500 spectators: approx. 200 000ft^2 (18 600m^2)
- a roof that would be economical to build, provide a durable and highly insulating cladding system, and accommodate spectators and athletes in a well-conceived interior layout
- exceptionally flat ice slabs: early in the design process a team of designers and speedskating dignitaries defined the 'world's fastest ice'
- mechanical systems for both long-term local community use (occupancy up to 500), and the Olympics when that number would grow 13-fold to 6500
- administration and support building with entry lobby, offices, locker and training rooms, judge and coach facilities, and miscellaneous functions – two levels plus basement totalling around 45 000ft^2 (4200m^2)
- maintenance facility, garage, and expansion of the existing refrigeration plant for additional cooling – around 5000ft^2 (465m^2)
- underground passage from the administration building to the refrigeration plant – about 10 000ft^2 (930m^2)
- landscaping, parking, and allowances for temporary facilities, power, and IT for the Olympics.

Adding the $1.6M of re-used refrigeration equipment to the project budget of $27M resulted in a budgeted unit cost of approximately $110/ft^2 ($1185/m^2) all-inclusive.

After establishing the interior layout, the team turned to the roof design. A low ceiling would best control air temperature and humidity, and Arup conceptualized three basic structural systems – parallel chord truss, tied-arch, and suspended girder. At the same time, SLOC solicited independent concept designs from two pre-engineered building manufacturers based on a brief performance specification prepared by Arup.

2. Aerial view.



3. Tension (red-yellow) and compression (blue-purple) in a typical long-span frame.

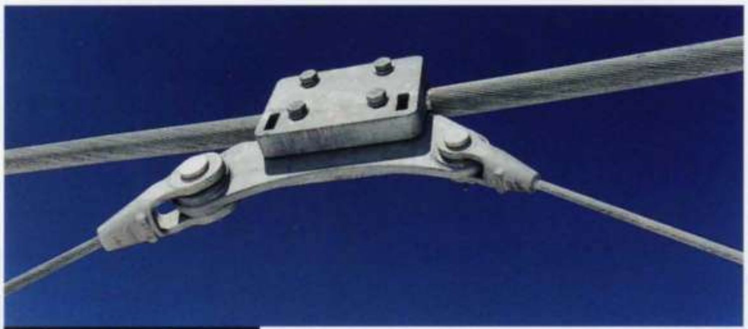
The suspended girder was selected, based on:

- *Appearance:* It has a simple but visually striking white-painted, exterior structure.
- *Interior height:* Because the suspension system is outside the roof envelope, the roof girders are only 36in (900mm) deep, and the interior height of 55ft (16.8m) was the lowest of all options.
- *Enclosed air volume:* The suspension system gave a 22% reduction over the next favourite, the truss roof system.
- *Cladding:* As in the truss scheme, the roof finish membrane was not visible from the ground, thus minimizing associated costs.
- *Constructibility:* Erection of one-way repetitive frames is straightforward.
- *Sustainability:* The suspension system had 45% less roof steel than the next lightest option, thus presenting the most sustainable choice.
- *Cost:* The design team considered the interaction of all major building components and determined that the most cost-effective solution was the suspended girder structure.

The LEED™ (Leadership in Energy and Environmental Design) process was developed by the US Green Building Council and launched during concept design.

LEED™ evaluates environmental performance from a whole-building perspective over a building's life cycle. The design team used LEED™'s objective methodology to assess the Oval, and their commitment to sustainable design gave the facility a head start toward a coveted LEED™ certification.

4. Hanging roof beam from the cable.



5. Close-up of cable clamp.

Structure

Roof

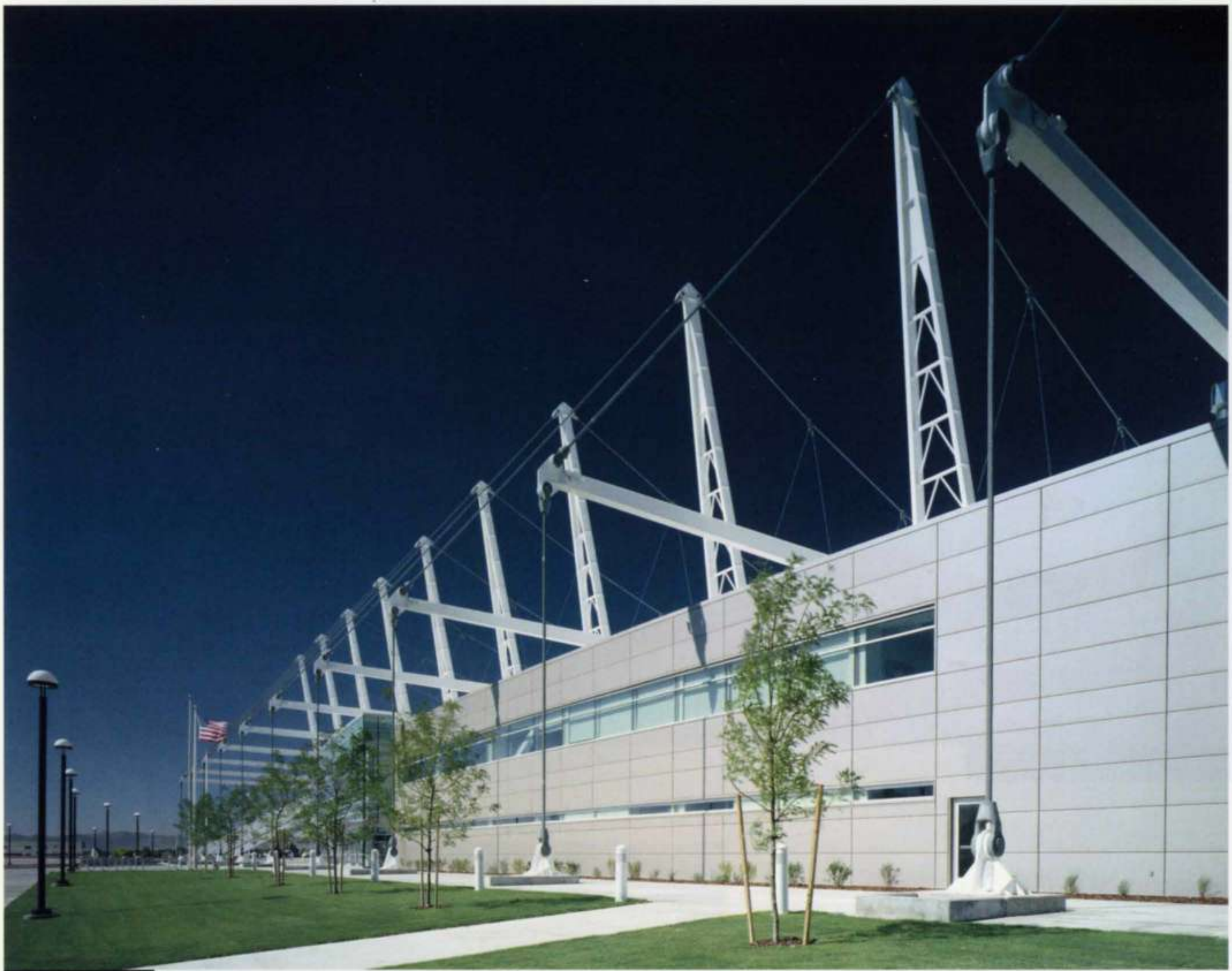
Due to its long span and sheer size - the roof structure was the largest element (c 30%) of the total project budget - successful integration of economy, appearance, and sustainability was crucial. Having selected the suspension scheme, the team conducted parametric studies to optimize structural form. Each structural member was optimized for minimum tonnage and detailing simplicity, and connection detail design was based on widely available fabrication techniques. These steps involved some iteration, but the period from start of schematics to completion of construction documents still spanned less than eight months. Once the steel contractor was selected, value engineering tailored the design to the contractor's capabilities and suggestions. Usage of recycled steel contributed to LEED™ certification.

The structure covers an area 310ft (95m) wide and 655ft (200m) long, with 3.5in (89mm) diameter spiral strand cables suspended between 12 pairs of masts 50ft (15m) apart on the long sides of the arena. The 20-ton (18 tonne) masts are 108ft (33m) tall, their upper sections cantilevering above the roofline and raking back at 11°. Lateral forces are resisted both by the lower mast sections and by diagonal braces in both directions. The main cables are anchored to the tops of the masts and to backstay cables raking at 45° to the extreme ends of the 65ft (20m) long booms. Vertical anchor cables tie down the boom ends to pile caps that resist uplift of approximately 650 kips (2900kN).

The cables have a 1:8 sag-to-span ratio, similar to a traditional suspension bridge, but the hangers are diagonal like the web members in a truss. This system has been used on some suspension bridges and long-span roofs in Europe, but not in North America. It significantly reduces roof girder bending moments under asymmetric snow loads, initial studies pointing to a 60% reduction in girder moments and higher stiffness.

It was thus possible to reduce both the weight of structural steel and the girder depth without substantially increasing the quantities or complexity of the cable system.

6. Roof installation.



7. Side elevation.

The roof was built with standard steel erection equipment and techniques wherever possible. The contractor erected the masts and backstay cables, hung the main cables from the tops of the masts with the clamps and hangers pre-attached on the ground, and then hung the roof girder in five straight segments, each nearly 70ft (21m) long. Bolted splices were used and the adjustable hanger ear plates were pre-attached to the girder segments on the ground.

Geometric control, from cable cut lengths to mast and girder fabrication tolerances, was rigorous, and only minor adjustments to the hanger ear plates bolted to the girders were required.

Ice slabs

The oval ice sheet requires a super-flat slab to achieve the uniform ice thickness, temperature, and hardness needed by athletes to break world records. The concrete slab specification is similar to those required in high-rack storage warehouses with forklift traffic - a very demanding specification with no point on the oval being more than 0.24in (6mm) off the theoretical datum elevation, nor any point deviating more than 0.095in (2.4mm) in a 10ft (3m) length. In addition, to achieve a world-record setting ice sheet the cooling pipes had to be at a constant depth from the top of the slab, there had to be no voids, and the hard and smooth surface finish had to contain virtually no cracks.

To make the world's fastest 0.71in (18mm) thick ice surface, a veritable sandwich of elements was needed - from top to bottom: a 7in (180mm) thick concrete slab containing the cooling pipes, two layers of rigid insulation with a greased two-ply slip-sheet assembly between, a 6in (150mm) thick compacted sand layer (with heating pipes to prevent the ice slab above freezing the ground below, resulting in heave), and a compacted granular road-base layer.

8. Tie down connection detail.

'Nine of 11 possible speedskating records have been set at the Utah Oval. Jochem Uytdehaage of the Netherlands was responsible for the most dramatic feat in shattering the existing Olympic record for the 10 000m by more than 15 seconds.'

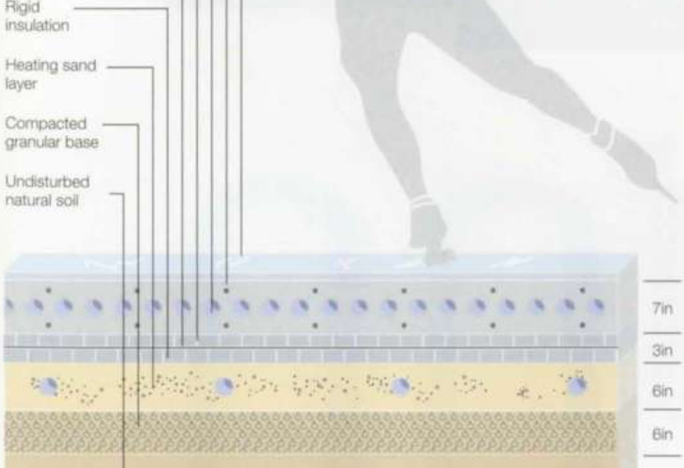
The team confronted several factors to achieve these tight tolerances:

- the natural tendency of concrete to shrink when it cures, which could cause fine cracking longitudinally and curling up of the edges transversely
- the unusual size of the pour: 12m wide, 400m long, nearly 1200yd³ (920m³), and no cold joints
- the congestion caused by 2.5in (64mm) cooling pipes at 4in (100mm) centers and heavy top reinforcement in both directions, especially in the two areas where the cooling pipes connect to the brine supply and return lines
- the natural buoyancy of the cooling pipes during the pour (pipes are sealed and pressurized during the pour to detect leaks).

The construction manager and the design team analyzed previous examples, and visited ice hockey facilities then being built in North America. Working closely with the ice consultant, construction manager, local structural engineer, and the client, Arup developed the design specification to form the basis for detail design that was finalized by the local structural engineer. Each party researched the aspects under their control and met frequently to arrive at an integrated solution.

Construction setback

On 19 April 2000 there was an accident as the last long-span frame was being erected. An anchor bolt group tying down the backstay cable ruptured completely, collapsing a mast, a girder, and a bay of roof joists. Two workers suffered minor injuries and all work was stopped. After exhaustive investigation, a remedial programme modified all 24 backstay anchor conditions by changing the uplift load path to new anchor bolts of suitable material. Arup worked closely with the contractor, client, and architect to develop the new design and implement the repairs, maintaining a full-time site presence from April through to structural completion in August. Arup's Advanced Technology and R&D Groups contributed to the investigation and assessment with a series of detailed structural and material analyses. Through teamwork the parties maintained their commitment to the project and the owner to achieve the immediate and long-term goals.



9. Section through the ice sheet support structure. Succesful integration of the various elements and achieving the exacting tolerances for the world's fastest ice resulted from close collaboration of the design and construction team members.

Mechanical

The challenge was to define clearly the widely varying system parameters for Olympic and subsequent long-term use, and then to craft economical, sustainable solutions. To efficiently gauge what was needed to handle an 'Olympic-sized' leap in demand, Arup studied historical weather data for Salt Lake City using purpose-designed in-house software, focusing on defining accurately the peak design conditions during February when the Games would happen. Salt Lake City is relatively dry, particularly in February and March.

The air-handling system is divided into four zones - a reasonably economical solution to providing minimum redundancy in the event of a single unit failure - and the use of space optimized by placing the units (AHUs) in the building's four corners outside the oval.

There are no established performance design criteria for humidity levels required by athletes, so humidity control was initially an issue of preventing condensation on the roof, frost on the ice surfaces, and fogging in the arena, by using the dehumidification capability of the chilled water coils in the AHUs combined with fresh air control and building pressurization. During commissioning, condensation appeared on the perimeter perspex protective screens around the central hockey fields within the Oval. Surfaces adjacent to the ice, with lower temperatures than the roof, were especially prone to condensation when the external conditions experienced a spike in wet bulb temperature. Also, there were issues of restricting infiltration due to heavy traffic in and out of the building. A system of dessicant dehumidification was added to provide background humidity control to 45%RH set point, a level that gave the operations staff sufficient time to investigate and monitor system response to rising internal humidity.

Normal training and recreational conditions can tolerate a wide range of temperatures in the occupied zone. 60°F (15.6°C) was the preferred temperature for skater comfort, but racing conditions required that the space temperature be lowered to 50°F (10°C), with the ice held at 20°F (-6.6°C). Maintaining 50°F(10°C) in the racing zone had proven difficult in several other arenas, largely because of high roofs. Whilst in the vaulted roof space of an airport terminal, say, it is desirable to have all the heat gains rise under buoyancy and form warm upper layers, in a speedskating arena where a large floor is held at 20°F (-6.6°C) it is often necessary to blow hot air to achieve 50°F (10°C) above the ice. It must be forced down into the floor zone - against its natural tendency to rise - without softening the ice.

The low interior height afforded by Utah's suspended girder system made conditioning the space more manageable.

Initial plans for the ventilation outlet configuration envisaged motorized nozzle jet diffusers, automatically adjustable to take account of the supply air temperature, but the cost proved prohibitive. The solution, both innovative and economical, was to configure the nozzles at the required angle for heating, with high-level automatic relief ducts that open during cooling to bleed some of the cold supply air away from the supply jets. Cold draughts are thus avoided during peak cooling conditions. This system also allow the operators some fine-tuning and control over the final system configuration, without having to adjust manually each of the 200 nozzle diffusers, at ceiling level above the ice. To further discourage stratification, this system was combined with placing the AHU return air suction grilles at floor level to remove air from the racing zone.

In tests before the Olympics, the systems maintained design conditions throughout the space with less than 1.5°F (0.56°C) variation at all locations in the racing zone and less than 3°F (1.11°C) variation between the racing zone and the ceiling condition. Interviewed in *USA Today*, the Oval's manager of operations and Olympic 'Ice Meister' Marc Norman acknowledged that he is 'generally credited with being the genius behind Utah's fast ice, but he's quick to credit the building design... *"We're probably able to control the environment better than any building has been able to in the past"*, said Norman.'

10. The arena's mountainous setting.

Electrical systems

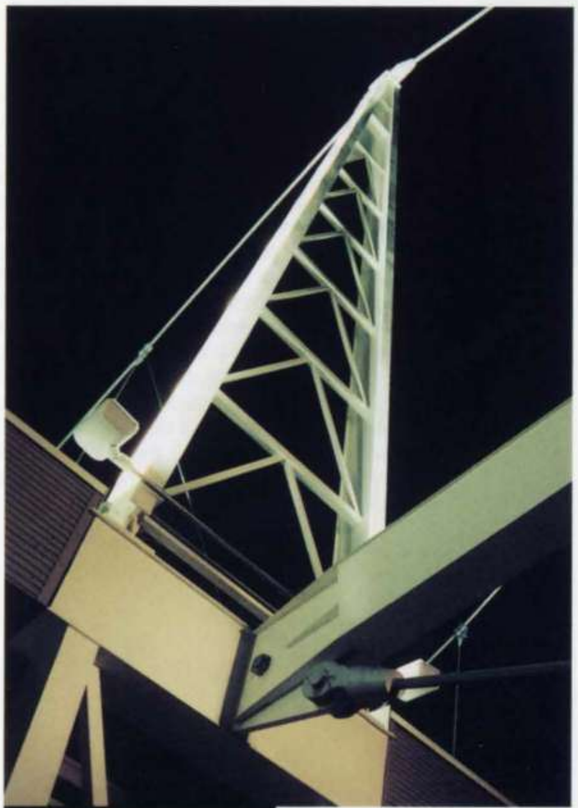
When SLOC chose to build the new indoor oval on the site of an existing outdoor facility, it made the first sustainable contribution to the project. The existing electrical system was retained to serve the existing ice plant, and a second utility transformer was added for the new building loads to bring the total available power to 4000kVA. Power distribution at 480V was chosen because of the building's relatively long distribution distances. Step-down transformers for receptacle outlets were provided throughout. An emergency generator was provided in accordance with building code requirements to give an emergency power source for life-safety systems only. Temporary mobile standby generation was also on hand during Olympic events. Connection points were provided for temporary standby generation, so that the building could function normally should the utility power become unavailable.

Olympic events increased the electrical demands from broadcast equipment, lighting, and mechanical systems. Permanent sports lighting for TV was, however, provided for after cost differences between it and temporary facilities were deemed minimal. Nonetheless, during the Olympics, the broadcast media teams installed additional, temporary broadcast lighting. As for other systems, an analogue addressable fire alarm system with voice evacuation capabilities was included. Energy efficient metal halide fixtures light the main arena, whilst the lightning protection system uses the structural steel to avoid an air termination network and down-conductors.

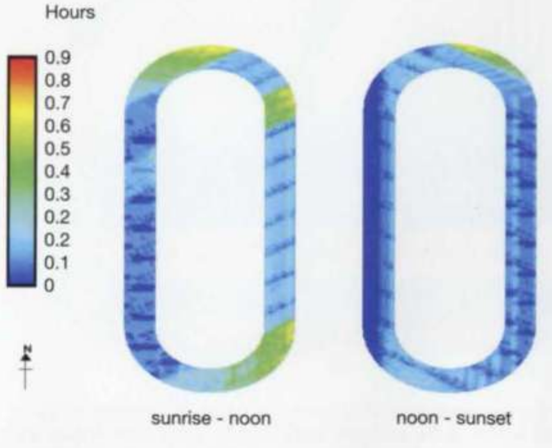
Daylighting

Daylighting was important, the challenge being to allow enough in for competitors and spectators to be aware of its presence, keep a sense of connection to the exterior, and benefit from the fuller spectrum of daylight, while avoiding potential deleterious effects such as sunlight affecting ice quality or causing glare. The arena has continuous clerestory windows on all sides, shaded by fabric roller blinds throughout except the north, which rarely has direct sunlight. The blinds diffuse sunlight and from most points in the arena the clerestory windows are visible, so the quantity of daylight is relatively uniform throughout the space. The Olympic event itself was not a concern since the windows were blacked out during competition for broadcast.

The material of the blinds was carefully considered, since some openness in the weave meant that a small proportion of sunlight would be transmitted directly (a trade-off in behaviour: a closed weave would have resulted in more glare) and the fabric blinds could cast a weak shadow. Arup developed computer analyses that took into account the building's complex geometry, the glazing characteristics, and the fabric blind performance, allowing the designers to determine where and for how long these attenuated beams would land. Their potential impact on the ice was then assessed. It was determined that the highest exposure, which can occur during the winter months, would still be well within acceptable limits.



11. Close-up of mast at night.



12. Daylighting analysis, showing accumulated indirect and direct sunlight exposure on the Oval ice.

13. Floodlighting highlights the structure.

Conclusion

In March 2001 the Utah Olympic Oval was among the first 12 buildings to be given LEED™ certification for sustainable design. The energy saving and sustainable design decisions were important, as the facility had not simply to shine for a mere two weeks in the world spotlight, but be a useful and enduring legacy for the community. This proved a decisive factor in obtaining LEED™ certification and, just as importantly, in gaining acceptance from the citizens of Salt Lake City.

The Utah Olympic Oval, now owned and operated by the Utah Athletic Foundation, a state government agency, was designed for flexible seating, with two hockey sheets at its centre for general recreational use. It is now a thriving recreational facility in the Salt Lake Valley, with a busy schedule of ice hockey matches, speedskating competitions, and programs to teach and promote speedskating. It is also the year-round training facility for the US Olympic Speedskating Team.

During the World Championships held in March 2001, US Olympic team member Casey FitzRandolph said, 'I'm a firm believer that the whole record book will probably be rewritten in February [2002]. The [Utah Olympic] Oval is built with the athlete in mind. The venue's temperature regulations inside, not to mention the thin air, are expected to contribute to faster times.' True words.

In the final speedskating event of the 2002 Games, Germany's Claudia Pechstein set her second world record, bringing the tally to eight world records set in 10 Olympic races. Nine of 11 possible speedskating records have been set at the Utah Oval, Jochem Uytdehaage of the Netherlands being responsible for the most dramatic feat when he shattered the existing Olympic record for the 10 000m by more than 15 seconds.

Awards

- Honor Award, American Institute of Architects (AIA) Utah Chapter
- Merit Award, AIA Western Mountain Region
- Gold Medal in AIA's 'Best Olympic Venue' Readers' Poll
- Innovative Design and Excellence in Architecture with Steel (IDEAS) Merit Award, American Institute of Steel Construction
- Excellence in Concrete Award, American Concrete Institute Intermountain Chapter.

Credits

Owner:
Salt Lake Organizing Committee

Post-Olympics owner:
Utah Athletic Foundation

Architect:
Gillies Stransky Brems Smith PC

Structural, MEP, and acoustics engineers:
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14. Interior artificially lit, showing shaded clerestory windows admitting daylight.

Michigan VIETNAM Memorial Monument

Leo Argiris
Patrick McCafferty

1.The Monument illuminated at night, showing the long horizontal cable overhead and the connections to the concrete plinth (left) and the free end of the arc (right).

Introduction

On Veteran's Day, 11 November 2001, the State of Michigan unveiled its Vietnam Memorial Monument at Lansing in a public ceremony attended by over 5000 veterans and their families. Designed to commemorate the lives of soldiers killed or missing in action in the Vietnam War, the Monument is a circular parade court within a 2.5 acre (1.0ha) veterans' park, three blocks west of, and on axis with, the dome of the State Capitol. Architect Alan Gordon designed the Monument, with Arup providing structural and electrical engineering services through several years of involvement. In total, the project took 13 years to reach fruition and cost US$3.4M.

Site and main features

The Monument's dramatic central element is a 120ft (36.6m) long steel arc, 10ft (3.1m) high and suspended 3ft (0.9m) above the ground, supported by a triangular concrete plinth and a cable system attached in turn to a 30ft (9.1m) tall steel pier. Completing the suggestion of a circle and facing the interior of the arc is a curved concrete bench - a place for quiet contemplation. Beyond is a field of engraved brick pavers commemorating individual veterans of all American wars; members of the community can publicly honour veterans in their own lives by sponsoring one of these stones. Beyond the Monument court is gently sloping landscaping with planted maple trees.

From an east-west walkway in front of the arc, visitors can view 15 engraved steel plaques lining its interior, inscribed with the names of Michigan's 2654 Vietnam War veterans killed or missing in action. These are arranged alphabetically within their home counties - strengthening the link to native soil. To aid navigation, county names are listed on cast bronze plates set in the ground perpendicular to the walkway. An engraved timeline of the Vietnam War is mounted on the arc's exterior. The key elements of the Memorial are lit at evening, with feature lighting accentuating the maples and the sloping landscape, reinforcing the boundary of the circular court.

Structural system

Arup worked with the architect to develop a system of cables and connectors able to suspend the 42 ton arc. A closed built-up steel box girder, this behaves as a propped cantilever with a spring support, connected to the concrete plinth via two steel box girder 'arms' and with its far end supported by the triangulated system of cables hung from the steel pier. The box girder's curved shape makes its vertical deflection depend very much on its torsional stiffness. In fact, the vertical deflection at the far end is nearly six times what it would be if it were straight.

*

'It's good the hometown finally remembered these boys'

a Michigan mourner at the opening ceremony of the Memorial Monument

*

The cables help prop the arc, reducing both the deflections at the far end and the forces at the rigid support. Each of the system's four cables has a specific contribution in supporting the free end of the arc (Fig 1). The skewed vertical cable, along the axis line to the Capitol dome but oriented 22.5° from horizontal, supports the vertical component of force. Because it is skewed, this cable imposes a horizontal component of force into the system, which in turn is resolved by the long horizontal cable. Spanning 92ft (28.0m) and suspended 10ft 6in (3.2m) in the air, this is a key architectural feature of the Monument, and the architect required that it be at least 2in (50mm) in diameter. However, this length and diameter meant that the horizontal component of force transferred into the system by the skewed diagonal was insufficient to stop the long horizontal cable sagging excessively, so a short horizontal cable was incorporated to add 30kips (133kN) of additional horizontal prestress to the system to limit the sag. Finally, the skewed diagonal cable, oriented 22.5° from both the horizontal and vertical planes, resists all lateral forces imposed on the arc. The four cables converge at a common connection, formed from a milled stainless steel hollow cylinder with internal threads. The end caps of the connection are also milled stainless steel with external threads and cylindrical sockets to receive the end fittings of the cables. The steel pier from which the cable system is hung is built up from 1.625in (41mm) steel face plates welded to three internal hot-rolled steel sections cantilevering from a large mat footing.

Assembly

The erection sequence clearly required careful consideration and analysis to ensure that the proper final arc configuration and prestress levels were achieved. The concrete plinth was cast in situ and the steel pier erected on-site while the steel arc was prefabricated off-site in two pieces. The halves were then brought to site, assembled on jacks, and splice-welded. After all the bolted connections between the concrete pier and the arc were secured, the latter's free end was propped 2in (50mm) above its true horizontal position. The two horizontal cables were then installed and prestressed to 100kips (445kN) each, care being taken to ensure that the free end of the arc did not move during the process. The skewed diagonal cable was then installed 'hand tight', and the jacks lowered until the free end of the arc displaced laterally by 0.5in (13mm), ensuring that an appreciable amount of prestress was transferred into the skewed diagonal cable. The skewed vertical cable was installed 'hand tight' and the jacks again lowered and removed. An electronic level transit verified that the free end of the arc was at its true horizontal position as the jacks were pulled away.

Expect the unexpected...

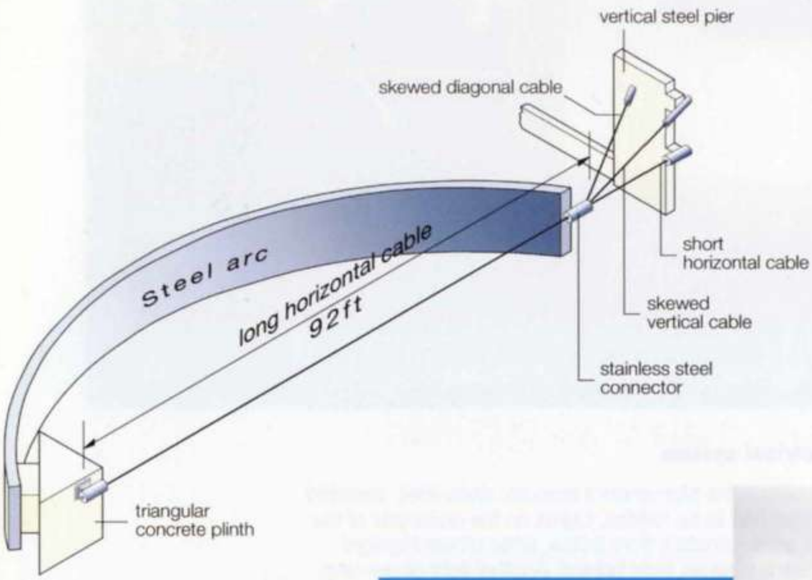
During assembly, the construction team discovered that the short horizontal cable had been manufactured too long and would therefore require additional jacking to achieve the prescribed level of prestress. Unfortunately, the jack ran out of stroke and the free end of the arc moved about 0.75in (19mm) laterally, the short horizontal cable apparently not receiving its intended level of prestress. The connections between the steel arc and its supports had been detailed to accommodate additional forces exerted on them arising from accidental imbalance of prestress between the long and short horizontal cables, so the arc and the cable system supporting it remained structurally sound. However, a purely aesthetic concern arose as, on warm afternoons, the short horizontal cable sagged a small but noticeable amount.

Though this had no structural consequences, Arup worked with the contractor to verify the cause.

Since the sag was most obvious on warm afternoons, it seemed to be a temperature-related effect exacerbated by the reduced level of prestress in the system. To test this hypothesis, Arup instructed the contractor to measure the vertical height of the cable at the connections and at the midpoint, noting the ambient air temperature and weather conditions, over a period of approximately three weeks. After analyzing this data, the Arup team identified a correlation between air temperature and the sag at midpoint. An empirical equation was then derived, based on the measured data, to determine the amount of axial force in the cable with respect to temperature.

Arup determined that the prestress in the short horizontal cable was about 5kips (22kN) at temperatures corresponding to those on the day the arc was de-propped. In fact, the 'measured' axial force in this cable varied from 6kips (26.7kN) at 29°F (-1.7°C) to 2kips (8.9kN) at 48°F (8.9°F), which corresponded to a measured sag of 0.72in to 2.47in (18mm to 63mm) at the same temperatures. The force was about 20kips (89kN) less than predicted by analysis when the initial prestress level in the short horizontal cable was set equal to the intended 100kips (445kN). To ameliorate the sag, prestress could be added to the cable, but the amount was temperature-dependent.

Arup recommended the equivalent of 20kips (89kN) of prestress be added to the cable on a cloudy, 38°F (3.3°C) day – similar to when the arc was originally de-propped. This would raise the prestress to the intended levels and thus eliminate the sag. Arup established a comprehensive data table of required additional prestress vs surface temperature of the steel arc to aid the contractor with the remedial prestressing procedure.



2 above:
Schematic of arc and cable system.

3 left:
The four cables converge at this common stainless steel connection at the free end of the arc: the long horizontal enters from the left; the three short cables exit from the right and attach to the tall steel pier.

4 right:
Connectors to the steel pier.

5 below:
Interior of the arc at dusk, showing cable connections to steel pier on the right.

7.
The long horizontal cable aligns with the State Capitol dome.

6.
Close-up of inscribed steel plaques, each with its own lamp.

Electrical system

To maintain the Monument's smooth, sleek lines, electrical services had to be hidden. Lights on the underside of the steel arc illuminate it from below, while others highlight the name plaques from behind. Another light glows atop the steel pier, and fibre optic cables light the glass strip along the axis line to the Capitol dome. A radial array of 54 luminaires set into the curved concrete bench frame the circular footprint of the Monument's parade court.

Electricity is routed from the local utility to an underground distributor west of the parade court, just inside the property line. Co-ordinating the conduits for lighting the arc into the triangular plinth was a challenge. They rise up within it and cross between the two support stanchions to run within the steel enclosure. Other than the fibre optic cable strip in the ground in front of the arc, all lighting fixtures are low voltage and incandescent. The lighting is controlled by photocell and time clock.

Conclusion

Michigan's Vietnam Memorial Monument demonstrates engineering expertise from design through construction and beyond. The team's problem-solving skill was put to work on issues both aesthetic and structural, and Arup's commitment to the project is ongoing. The results in terms of public support of the Monument were well worth the effort. Even before the official unveiling, the Monument was highly anticipated and welcomed particularly by local Vietnam veterans, some of whom on their motorcycles led the convoy of trucks carrying the pre-assembled arc. Once on site, the veterans stayed nearby to observe construction and informally stand guard through the night. The veterans and their families had waited decades for a local, public, and permanent tribute to their contributions in the Vietnam War.

The warm reception can also be attributed to the design's effective use of simple geometric forms. While the impressive span of the suspended arc provokes a sense of unease and unresolved tension, its circular form with the names it immortalizes also embraces and comforts visitors. The fact that the components were manufactured in the Midwest - many in Michigan - also contributes to the local sense of pride in the structure. One local newspaper quoted a mourner at the opening ceremony: 'It's good the hometown finally remembered these boys.'

Credits

Owner:
Michigan Department of Management and Budget/ Vietnam Monument Commission of Michigan

Architect:
Alan L Gordon

Structural and electrical engineer:
Arup Leo Argiris, Khalid Eid, Patrick McCafferty, Tom Smith, Valeriy Sokolov, Margarita Vanguelova, Seth Wolfe

General contractor:
The Christman Company

Steel fabricator and erector:
Union Fabricators and Fitters, Inc.
TriPyramid Structures, Inc.

Steel detailer:
Strenn Consulting Group, Inc.

Illustrations:
1, 4, 7: Patrick McCafferty
2: Margarita Vanguelova / Sean McDermott
3: Leo Argiris
5: Gary Bjorkquist
6: Janice Meyer Gordon

Sustainable transport

Adrian Gurney

What is sustainable transport?

Since the Rio Earth Summit, 10 years ago, there has been a major change in understanding of the likely long-term environmental effects of developed and developing economies related particularly to energy use, loss of habitats, and effects on air, water and soil quality, and health. Transport impacts, particularly with increased car ownership and use, are implicated - with transport responsible, for instance, for over half the nitrogen dioxide measured in the local environment across the UK[1] (Fig 1).

The concept of 'sustainability' is based on the idea of stewardship – understanding that we have responsibility in our decision-making for what we pass on to future generations. With transport policy and its major influence on long-term urban form, location, infrastructure and the environment, the stakes are particularly high. As the debate on sustainability developed in the 1990s, it became clear that decision-making had to take into account not just economic and environmental issues, but also social ones. Transport is at the core of these concerns. A reliable and efficient transport system to support the economy is needed, but there are acknowledged health and environmental effects that need to be addressed. And there are major issues of equality of access, safety, and security (Fig 2).

The solutions have been seen mainly in terms of the extent to which it is possible to reduce travel - in particular the use of the car and lorry - and increase use of public transport, walking, and cycling. If current trends could be reversed then the perceived benefits in terms of reduced road congestion, lower pollution, and increased health and safety would help to reinforce the change.

The goals are seen in terms of trends, of a general increase in sustainability, and the experience in some countries or cities is often used to illustrate what is achievable[2].

What progress?

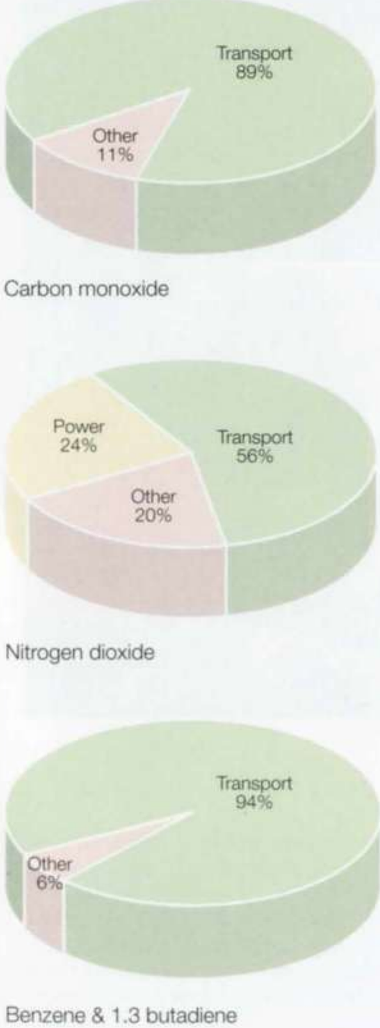
Three key threads of change need to be examined:

- *the extent to which car use can be reduced by measures like taxation, including the taxing of fuel, road space, and parking*
- *the ability to improve facilities for non-car users, including improved levels of service and infrastructure for public transport and for pedestrians and cyclists*
- *the opportunity to integrate land use and transport planning to reduce the need to travel and support use of non-car modes by, for example, concentrating development within urban areas.*

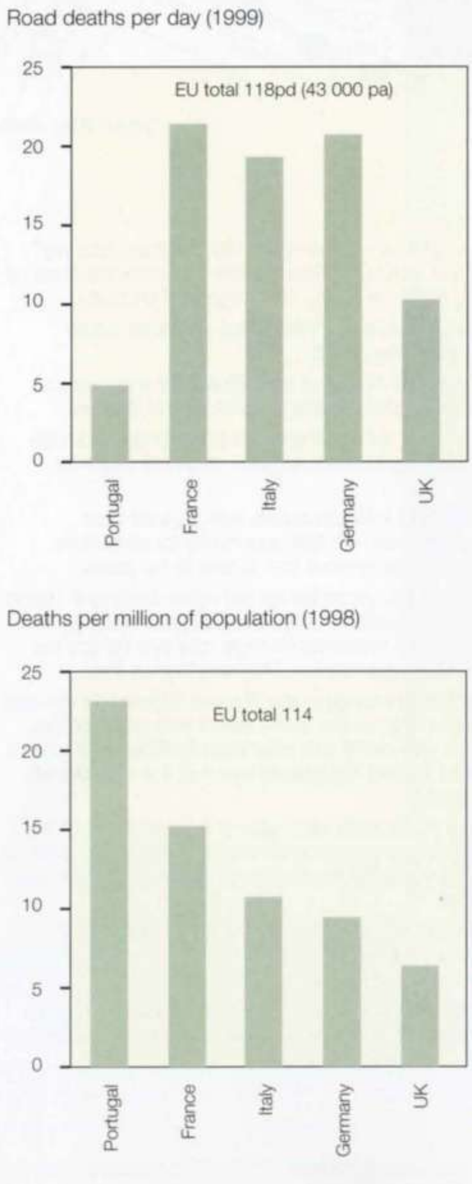
These three principles of policy change were established in the early 1990s in the UK and the EU. Clearer guidelines on what may be achievable were developed from the mid 1990s, in much of which Arup played a significant role[3,4]. Several issues, however, have affected implementation.

This text continues on page 41: ▶

1. Pollutants and their source in transport.



2. Road deaths in EU countries.



Case study: Ilford Town Centre

3. A new Town Hall square for Ilford.

4 below: The Kenneth More Theatre, Ilford.

5 right: Ilford Station.

6. Ilford Market.

Ilford is a large and relatively prosperous town centre within the 'Thames Gateway' region on the east side of London. Arup (with CB Hillier Parker) was commissioned by the London Borough of Redbridge to carry out a long-term regeneration study.

It was soon clear from local surveys and consultation that several significant issues needed to be addressed by the multi-disciplinary team:

(1) Ilford is facing increasing competition from the out-of-town Bluewater and Lakeside centres, and change at the nearby outer London centres of Romford and Stratford.

(2) Ilford is not functioning well as a focus for the community life of Redbridge Borough because of the limited range of non-shopping facilities, and lack of central space for meeting/activities.

(3) There are severe problems of connectivity in Ilford's centre, with a partial inner ring road causing severance, an elongated core with little opportunity for pedestrian exploration, and local congestion affecting bus services and access to car parks.

The team was convinced that the sustainability principles set out in the document 'Heroic Change'[8] needed to be explored for Ilford in order to provide an integrated strategy for transport, urban design, and land uses - thus improving strategic connections and the local environment, and enabling sustainable regeneration. The main themes are:

- *to make Ilford one of the major centres of change in the Thames Gateway in the next 30 years, with over 5000 new homes in the centre, and a mix of new retail, offices, and other uses (including restaurants and health and education facilities) to a total of 700 000m^2 (nearly one and half times current floorspace) much of it in high density, medium rise, mixed use developments.*
- *to overcome the artificial constraints of the inner ring road on the expansion of the town centre by removing the local one-way system and designing the main routes as boulevards. This would be achieved by altering junctions and crossing facilities, and would improve environmental quality.*
- *to provide a new station square directly linked to the main centre, a network of pedestrian and cycle routes directly linking the main attractions, and a more intelligible access to the centre for cars (with easier links to car parks).*
- *to concentrate the early stages of implementation on a few priority areas where a major change in activities, high quality new buildings and spaces would fundamentally alter the perception and use of the town centre (Fig 3).*

The strategy, which has been the subject of significant local consultation from the initial considerations of objectives through to specific solutions, has been well received both by the Council and local business and community groups.

The Greater London Authority and Thames Gateway Partnership have also welcomed it - and now see Ilford as an important contributor to sustainable change in East London.

Text continued from page 39:

Firstly, Increased taxation is difficult to justify unless it reflects the internalising of external costs, is directed towards supporting the alternative means of transport through hypothecation, and is seen to fall equitably on different populations. Secondly, public transport has been the subject of major experimentation in organisation, particularly in the UK, in order to increase efficiency, raise sufficient investment capital, and address market needs. Thirdly, the urban renaissance agenda in the UK and the EU has given additional support to the land use / transport planning focus[5], but underlines the significant problems experienced in the majority of existing low density suburbs and in rural areas[6].

The two major transport initiatives by the UK government in the last few years - the White Paper 'A new deal for transport' of 1998, and the 10-Year Plan for Transport of 2000 - need to be seen in this context. They contain some ambitious goals such as reducing congestion below current levels despite increasing car ownership, and increasing the number of rail passengers by 50%. However the success in implementing particular initiatives has so far been varied:

1. There has been limited take-up of the opportunities for a workplace parking tax and congestion charging, with London alone making real progress.

2. The Strategic Rail Authority has made little impact on the long-term planning of the railways, though the current severe crisis may mean greater changes here.

3. Regional transport strategies and local transport plans have resulted in more balanced proposals and funding, but integration with land use planning - particularly outside the main urban areas - has been very variable[7].

What future?

Transport does come to the top of the political agenda in the UK when a crisis in provision is experienced. The difficulty is that addressing the underlying issues cannot be undertaken only in the short term. There are long-term problems in terms of infrastructure, organisation and established travel patterns and behaviour, and hence a need for more fundamental progress. There are three areas of change, and they are proceeding at different rates, which could be significant in the longer term.

Firstly, financial and other measures to induce fundamental change are strongly dependent on political will and an alteration in public perceptions. This involves recognition of the importance of de-coupling transport energy consumption from economic growth - which in turn means, for example, encouraging the use of less fuel-intensive modes, increased support for improved public transport infrastructure, and increased taxation of private vehicle usage to pay for it.

Also involved here is the improved technological design of vehicles. This includes the use of new power sources (gas, electricity) so that vehicles generate minimal environmental pollution, and the production of niche vehicles such as neighbourhood cars that can be rented for specific local use – encouraged by an appropriate tax regime.

Secondly, changing responses to other current issues, such as use of information technology, may also have some long-term effect on the efficiency and sustainability of transport systems. The use of IT can release workers from regular commuting, enable home delivery of a range of products on a regular basis, make it possible to provide neighbourhood transport accessed via a secure web site, and improve information on public transport services.

IT can also improve interchange logistics for freight transport, enabling transfer to more sustainable modes. It can assist in traffic control, thus providing a more sensitive regulation of road conditions to achieve more sustainable usage, including automatic road pricing.

Thirdly, changes in public planning and development are beginning to have positive effects and could be further strengthened through the continued integration of land use and transport planning. This can lead to concentrating higher density new development within or adjacent to existing urban and suburban areas - or in main settlements in rural areas - where it is possible to provide a wide range of facilities and public transport services[8].

Alongside this, improvements should follow in the design of local environments. This includes residential, recreational and commercial areas with low vehicle speeds, improved walking and cycling facilities for local journeys, and a greater mix of uses to enable greater local activity[9].

Conclusions

It took two generations to move to dependence on the car: the 1920s to the 1950s in America, and the 1950s to the 1980s in the UK and Europe. It is likely to take a further generation to achieve a more sustainable transport system. If that change is to be achieved, it will be because of a wide range of factors coming together - some of them planned, others driven by external factors (such as an uncertain or expensive energy supply, or an environmental crisis).

Meanwhile there are opportunities that can be pursued, and Arup is playing a significant role through its ongoing research work for the UK government and others on walking and cycling[10] (Fig 7), and its involvement in specific projects[11] (Case Study: p40).

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'Arup is playing a significant role in developing sustainable transport options through its ongoing research work for the UK government and others, and involvement in specific projects.'

7. Pedestrian and cycling zones can improve urban quality of life.

Credits

Arup contributors to the documents referenced above:

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Illustrations:
1-7: Arup

This paper is based on a lecture by Adrian Gurney at the University of Cambridge Department of Land Economy, in February 2002.

The Imperial War Museum, London

Stage 3

David Pearce   Annelise Penton

1. West façade of completed building.

2. below: Stage 1 exhibition gallery, before construction of Stage 3 extension to the barrel vault.

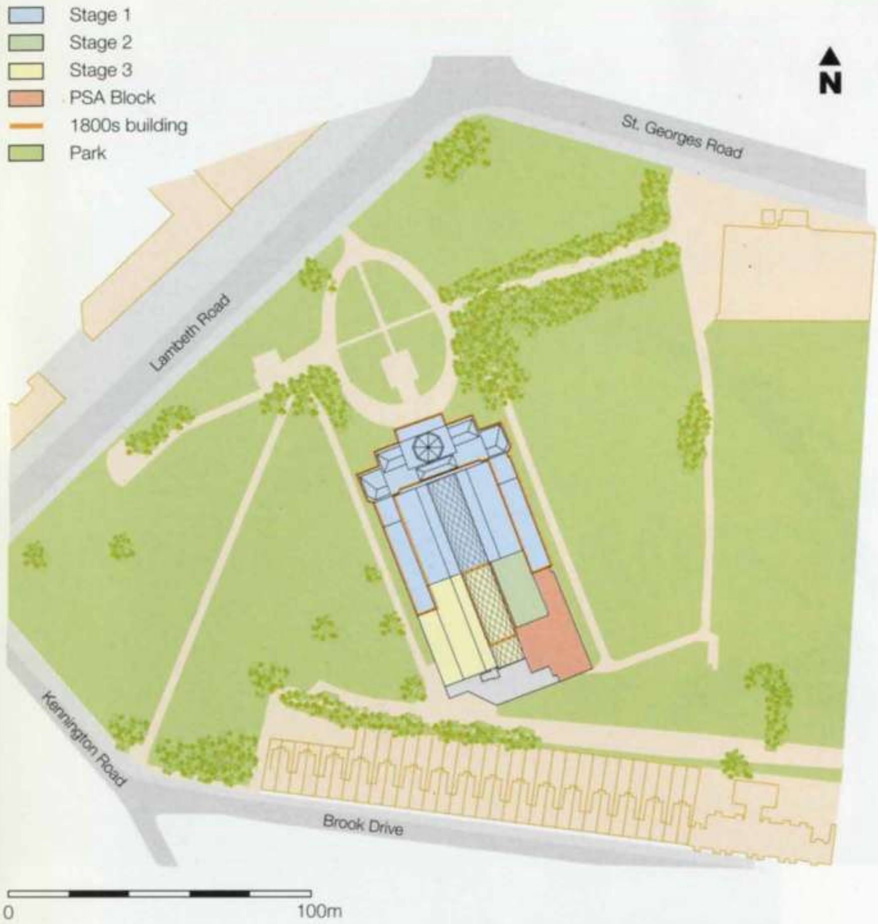
Introduction

Built in 1815 as the Bethlem Royal Hospital, the Grade II Listed building on Lambeth Road, Southwark, SE1, became home to the Imperial War Museum in 1936. In 1983 the IWM approached Arup Associates to explore the feasibility of developing the building into a world-class home to this national collection. The brief was for a masterplan and design that significantly increased the amount of gallery space, provided strict environmental conditions appropriate for a national museum holding a large and diverse collection, and improved visitor facilities. Arup Associates proposed a four-stage development, the first to be carried out whilst the Museum was closed to the public and subsequent stages realised when it was fully functioning, at later dates.

The scheme went ahead. Stage 1 created, as a focus to the Museum, a top-lit central exhibition hall plus various exhibition and art galleries around it, giving a total of 8000m² of museum space, 4600m² of it new. An exposed steel structure and diagonal lattice barrel vault provides support for aeroplanes and other large exhibits suspended in the main atrium space[1]. The second stage - completed six years later in winter 1994 - was the exhibition and art galleries in the south-eastern lightwell. This added another 1600m² of floor space and, as planned, was carried out with the Museum open to the public.

In 1995, the IWM asked Arup Associates to review the original masterplan with respect to the final development stages; approaches had been made both to and by the IWM for the Museum to house the UK's first permanent exhibition on the Holocaust. The brief was for a conceptual study to explore maximising exhibition space within the original masterplan's envelope, whilst not prejudicing the potential for a fourth and final stage of redevelopment.

3. Stage 2 gallery space.



4. Location plan.

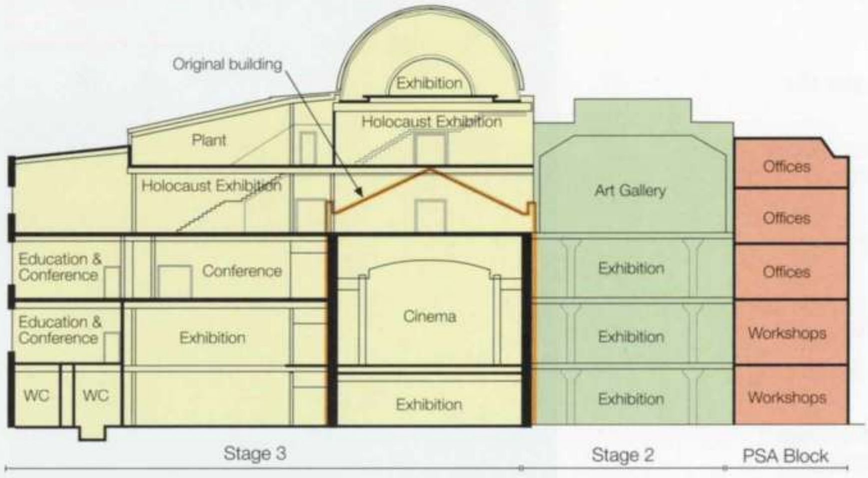
The site

The Museum lives in several interlinked buildings within Geraldine Mary Harmsworth Park in Southwark. At the north is the horseshoe-shaped 1815 brick building of the Bethlem Hospital with its Stage 1 central infill. South-east of this is a 1960s brick and concrete building (the PSA block), containing document storage, offices, workshops, and other back-of-house facilities. In the centre is the cinema block - also originally part of the Hospital accommodation.

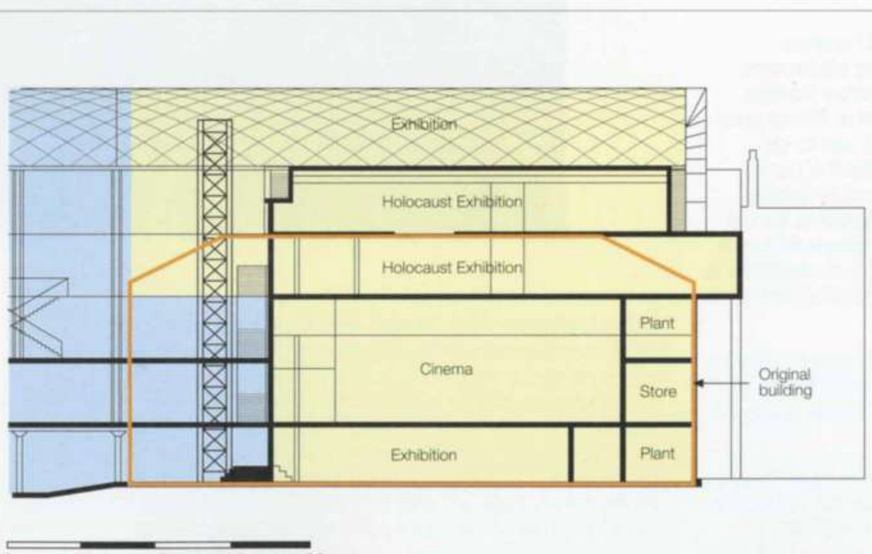
A courtyard originally between the PSA block and the Stage 1 area was infilled during Stage 2. There remained a double-storey gallery space to the western boundary - the only double-height exhibition space outside of the main, Stage 1, atrium. The area available for Stage 3 was the south-west corner of the building at the lower levels, to build out over the existing cinema building with an extension of the Stage 1 barrel vault roof.

The Museum has tight site constraints. The Park is owned by Southwark Council and therefore unavailable for further building. Development was constrained by the boundaries of the existing Museum land and the height of the existing listed building, with its relationship to neighbouring residential streets. The nearness of houses to the south of the Museum stopped the building mass extending southwards to the boundary at the existing height; the southern extreme is the service yard, the only servicing and exhibits access point into the Museum, and enclosed by a single-storey wall. The fourth and final stage of development was proposed as building over the service yard, but during design of Stage 3 the IWM decided this was unlikely ever to progress.

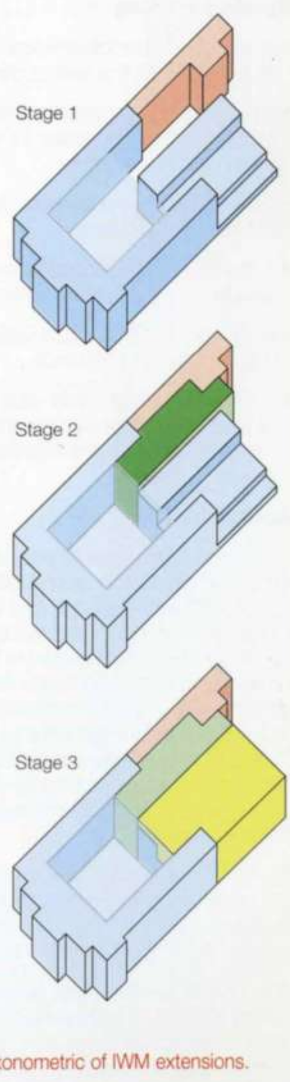
Construction in and around the existing, operating buildings was just one of the project's challenges. Beneath the Museum runs the Bakerloo Underground line, another constraint on the development, this time on its foundations.



5. Cross-section.



6. Stage 3 section



7: Axonometric of IWM extensions.

8 & 9. Glass screen between gallery and atrium areas.

The brief

Building anatomy

- emphasis on the importance of the main stair plus its extension to the new upper levels
- a new, secondary, entrance for conference, disabled, and schools, with foyer space for gathering large numbers of schoolchildren together
- easy access to the schools' facilities from the schools' entrance
- closeness of the secondary entrance to the main stair to enable easy public orientation within the Museum
- prominence of Holocaust Galleries when first entering through the front entrance
- lengthening of the barrel vault to the southern extent of the Museum (as per the original masterplan) to both link the various stages together and create a proportionally pleasing roofline.

Accommodation

The Stage 3 brief was to provide a variety of spaces: exhibition areas; education facilities including classrooms, support office, dining hall, and WCs; conference facilities including cloakrooms and WCs; and a cinema. The cinema had in fact been refurbished in Stage 2 and was to be retained in Stage 3, although this would entail the partial demolition and reconstruction of the area and its finishes. The education facilities were to provide classrooms for the Schools Programme – an active part of the Museum's local and national remit - during term-time, and for conferences at other times, enabling the Museum to maximize its additional revenue potential.

Most of the exhibition space was for the Holocaust Galleries, with various additional areas for temporary exhibitions. This included reinstating a double-height gallery space at ground level for large and potentially heavy items.

The brief required spaces which, through their location and quality of finish, could provide this dual schools / conference role for the Museum, plus one that could be separately accessed for additional security and to provide out-of-hours and ticketed access.

As for building services, Stage 3 was to provide a variety of fully air-conditioned exhibition spaces, plus classrooms with natural ventilation supplemented by some comfort cooling to deal with the afternoon overheating that could occur because they faced west. The location of existing plantrooms, plus lack of capacity in the existing cooling, heating, and heat rejection plant, made a new plantroom necessary that did not heavily impinge upon available area for exhibition space. The main boilerhouse and chiller room was in the cinema block, and thus within the construction site of the Stage 3 works.

10. Close-up of main staircase at the upper levels, showing the link between the Stage 1 and Stage 3 barrel vaults.

The design - scheme

As the demand for a permanent Holocaust exhibition grew, so did the feasibility of constructing Stage 3, as funding was in place from several sources including the Heritage Lottery Fund, Jewish groups, and private individuals.

Early in the design, the team decided for three reasons that the external aesthetic should respond to that of the adjacent existing wing. Firstly, the development was not to upstage the Museum's main entrance, but be clearly integral to the whole. Secondly, the building's Grade II Listing would preclude an overtly high-tech scheme unless there was much consultation with English Heritage and the planners, and even then an acceptable Planning Approval could not be guaranteed. Thirdly, the brief's deployment of spaces was particularly suited to 'windows in a solid façade' rather than a predominately glazed elevation.

It was felt that, for the redevelopment's overall coherence internally, the structural language of Stage 1 should be continued. Stage 3 was thus developed as a lightweight, fully expressed steel frame with restraint given by concrete stair / lift elements. It was also necessary to maintain full structural separation from the existing adjacent west wing and cinema block.

The design team reassessed the servicing strategies developed during Stages 1 and 2, both for their relevance to the current and anticipated future Museum, and to test whether the Stage 2 modifications had proved appropriate for the spaces' eventual use.

As Stage 3 was a variety of spaces 'slotting in' around existing volumes, it was readily apparent that only the upper levels could supply the clear expanse of floor plate needed for the Holocaust exhibition. The ground floor level at the rear of the Museum (Level A) was actually the 'basement' level from the main entrance, enabling access at grade via the new schools' entrance on the west side.

(See panel below)

Similar patterns of movement were expected for conferences, so the two uses dovetailed and enabled a simple accommodation plan to be developed. The foyer / gathering space was proposed as an exhibition gallery immediately next to the new schools' entrance; the space was originally part of the Museum and not big enough for useful temporary exhibition space. The schools' dining area and classrooms were located along the western boundary where they could enjoy good natural daylighting and views out over the Park. These spaces wrap around the larger volumes of exhibition spaces and conference room.

For the first time at the Museum, Stage 3 was to include accommodation more than 18m above ground level. Usually, under Section 20 of the London Building Act, this would require the design to incorporate a fire-fighting stair and lift, but the Museum does not operate during a fire situation as a 'normal' office or public building. When a fire alarm is triggered, no immediate general alarm is sounded.

Patterns of movement planned for schoolchildren accessing the Museum

Around 80 schoolchildren per hour were expected, so clearly the logistics of moving, gathering, and servicing the children's needs would be the primary driver for the internal planning.

The flow would be:

Arrival -> cloaks -> WCs -> foyer gathering for briefing -> dispersal into Museum/classrooms

And subsequently:

Foyer gathering -> collection of lunch boxes from cloaks -> WCs -> dining hall -> dispersal into classrooms/Museum -> WCs -> exit.

'The galleries have been extremely popular, also the education facilities have enabled the Museum to expand its education programme as well as increase additional revenue through conference use.'

Instead, it shows as a warning in the main control room at the north end of the Museum, and a staff member is sent to investigate. If it is found to be a 'real' alarm, the control room is contacted by radio and the Fire Brigade advised. At this time evacuation messages are broadcast throughout the Museum, ensuring a quick staff-assisted evacuation away from the fire source.

A combination of the Museum's strict regime, plus negotiations between Arup Associates, Arup Fire, and the London Fire and Civil Defence Authority, enabled the requirement for a fire-fighting lift to be waived.

The floor area above 18m was minimal: with a small occupant capacity as it was classed as 'art gallery' not 'place of assembly'. A fire-fighting stair was located within the rear yard of the Museum, at the southern end of the Stage 3 works. This conformed in all aspects to the requirement, and gave access straight to Level E of the Museum. A separate straight stair then led from level E to F, the topmost floor.

This was in addition to a combined fire and accommodation stair on the Museum's west side leading direct to Level D, with associated (fire escape only) stairs then linking up to the northern end of levels E and F. Provision of two separate and discreet escapes from relatively small floor plates reassured the authorities that the Stage 3 design offered a safe alternative to the usual requirements.

The design – building

A 6.2m x 8-10m (ie variable) structural grid was adopted, accommodating the servicing strategy and structural rhythms set by Stage 1. Structural separation from the cinema block was achieved by inserting a 'table top' structure where its roof previously was. Two 2m deep box girder beams, each in two 11m lengths, were placed within the cinema walls, supported on CHS steel columns threaded through the existing floor plates and onto new pad foundations.

The box girders support primary and secondary steel beams, which in turn carry *Holorib* decking with concrete slabs. Elsewhere, the primary steel beams, carried on CHS steel columns, defined Stage 3's circulation routes which also carried the primary services routes from which each space teed-off. The secondary steel beams, above and at 90° to the primary beams, define the ceiling rhythm, and within this zone the air supply and extract ducts, plus the power and lighting tracks, run.

The 'aesthetic upgrading' of ceilings and services developed in Stage 2 had proved unnecessary, given how the Museum uses its exhibition space. Its designers develop the spaces as 'warrens' of story-telling, with ceiling details often masked by exhibition fit-out, so it was decided that the Stage 3 design should revert to the Stage 1 principles:

- exposed structural soffits
- exposed oval supply and return ductwork with linear slot diffusers
- lighting and power tracks running between the air ducts to provide fully flexible cabling to exhibits
- acoustic absorptive material between the services elements on the slab soffit to create an acoustically comfortable space
- electrical services floor boxes on a regular grid to allow connection of display cabinets once exhibition designs have been finalised.

Museum galleries require stable environmental conditions, within a narrow band of temperature and especially relative humidity to help preserve exhibits. However, heat and moisture loads within these spaces vary dramatically as groups of visitors move *en masse* from one exhibit to another. Simultaneous control of conditions is maintained by triple redundancy temperature, humidity and CO_2 space sensors controlling a variable volume air system. Carbon filtration is provided to maintain clean air supplies for the protection of exhibits.

The classrooms are naturally ventilated with supplementary cooling. The meeting and conference rooms are mechanically ventilated and fan coil units provide supplementary cooling / heating. The restrictions of the refurbished cinema and its requirement for flexibility of use suggested the design of high-level supply diffusers with low-level extract at the front of the stage and the rear wall of the cinema. New air-handling plant was provided behind the stage area. The trademark 'style' of the previous stages was reinforced within the Stage 3 design. The requirement for flexibility of spaces, and nature of the exhibits, produced an aesthetic where the structure and services elements generated the architecture.

The design – enabling works

Prior to the Stage 3 works, the Museum had four major plant areas:

- Level A boilerhouse - at the south end of the building and housing boilers, chillers, and pumps serving the whole Museum
- roof-top cooling towers – above the southwest wing
- Stage 1 air plant – in the roof void above the east and west wings to either side of the main atrium
- Stage 2 air plant – south of the Stage 2 infill works.

Some of this plant thus fell within the area to be redeveloped in Stage 3, and a major enabling works package lasting six months was required. This entailed inserting new cooling towers at roof level above the Stage 2 works, the removal of a standby chiller outside the main boilerhouse, and the termination of all mechanical and electrical services which fed from the Stage 1 and 2 areas into the Stage 3 site area.

All this was exacerbated by a lack of detailed records of service runs / connections, plus the complexity of the main boilerhouse area, which had never been thoroughly overhauled – redevelopment had previously been piecemeal, generally within restricted spaces, without all the redundant service runs being taken out. The removal of chillers / boilers to new locations in order to insert additional chillers, plus re-locating all the pump sets to a new pumproom created immediately adjacent to the boilerhouse, was all carefully planned and implemented.

The Museum was in continuous operation and services had to remain live to maintain environmental conditions. Routing the new service connections between the new cooling towers, the re-modelled boiler / chiller room, and the Stage 3 plantroom was complex but rewarding. It is a testament to the planning and design that the Museum did not have a single day with any compromise to the environmental levels.

The Stage 3 plantroom – housing air-handling plant, water treatment tanks, and lift motor rooms - was located at Level E, beneath the roof like the Stage 1 plant. The difference, however, was that in Stage 3 the area east of the plantroom was part of the Holocaust Exhibition Gallery, with stringent acoustic separation criteria.

The cinema could not stay in use during construction - due both to the structural insertions and the services connections, which had to be incorporated beneath the cinema stage - so the Museum relocated cinema facilities to the art gallery designed by Arup Associates in Stage 2. This considerably reduced the number of interfaces between the public and the construction site. Similarly, the schools' facilities to be lost during construction were re-housed in temporary accommodation in the Park east of the Museum. This freed the Museum's west side for contractor access and facilities only - maintaining a healthy separation between children and the site.

Construction

The length of the construction programme for Stage 3 - three years - reflected the various complexities of working around an existing building, working within a fully functioning museum open to the public throughout, inserting new foundations and structures around existing 19th century foundations, and working with existing services and modifications to these services.

11 & 12. The Holocaust exhibition.

Conclusion

The Stage 3 extension, with particular attention on the Holocaust Galleries, was opened by HM The Queen on 6 June 2000. The galleries have been extremely popular, with the Museum introducing timed ticket access to prevent overcrowding in the early months of opening. The education facilities have enabled the Museum to expand its education programme as well as increase additional revenue through conference use.

Reference

(1) AYIOMAMITIS, A *et al.* The structure of the Imperial War Museum extension. *The Arup Journal, 23*(4), pp2-6, Winter 1988/89.

The interfaces between the site boundary and the public were carefully monitored, with 'crash decks' built over the main stair, and a scaffold and insulation board 'wall' within the main atrium from D floor up to the underside of the barrel vault roof. This insulated the Museum from dust, noise, and thermal change for much of the works.

During construction, the Museum let the contract for the design and construction of the Holocaust Galleries. Several co-ordination meetings were held with the gallery designers (DEGW and Amalgam), but the base scheme's lighting, power, and air systems were flexible enough for the design to be carried out without alterations to the base scheme.

The structure and fabric of the building were kept simple:

- concrete pad foundations
- steel frame
- concrete cores for stability
- load-bearing masonry external walls with a lime mortar to match the original building and to preclude the need for movement joints
- *Holorib* decking with 150mm or 300mm concrete slabs
- tubular steel lattice barrel vault
- profiled metal roofing panels.

Complexities lay at junctions with the existing fabric: with 'soft' joints where floor slabs abutted, with the separate foundations, and in particular at the junction between the old and new barrel vault structures. The new barrel vault was delivered to site in sections, and then assembled on a framework built off the Level F floor slab and site-welded together. The northern sections were welded to the tubular 'hoop' at the southern end of the existing vault.

The Stage 1 vault had been covered in polycarbonate, but the team decided to roof the Stage 3 vault with a metal sandwich panel, for three reasons:

Firstly, 'new' polycarbonate contains additives to prevent discolouration, but the existing vault had yellowed over its 15-year lifespan, so the new could never match the existing.

Secondly, there are inhabited gallery spaces within the vault space (unlike Stage 1) and the cooling load that would be created by using polycarbonate was unacceptable both environmentally and physically.

Thirdly, fully daylit gallery space is not flexible for exhibitions, so would have been very restrictive to the usage of the Level F area.

Credits

Client:
Imperial War Museum

Designers:
Arup Associates with Arup specialists: Simon Barden, John Beckwith-Smith, Paul Dickenson, John Edgar, Chris Holmes, John Hopkinson, Rebecca Hutt, David Hymas, Daniel Jang-Wong, Mike Kinney, Dick Lee, Graham Ling, John E Miles, Terry Moody, Eric Owen, David Pearce, Annelise Penton, Terry Raggett, Alan Ross, Joe Solway, Geoff Stevens, Simon Webster, Jim Warren, Malcolm Wright

Main contractor:
Birse Construction Ltd

Illustrations:
1, 8, 10: Andrew Putler
2, 3, 9: Arup Associates
4-6: Claire Noble
7: Annelise Penton / Emine Tolga
11, 12: Courtesy IWM / Andrew Putler

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