THE ARUP JOURNAL

MILLENNIUM ISSUE 3 2/2000

THE ARUP JOURNAL

Vol. 35 No. 2
2/2000 (Millennium issue 3)

Published by
Ove Arup Partnership Ltd
13 Fitzroy Street
London W1T 4BQ
England

Tel: +44 (0) 20 7636 1531
Fax: +44 (0) 20 7580 3924
website: www.arup.com
e-mail: corporate@arup.com

Editor:
David J. Brown

Art Editor:
Desmond Wyeth FCSD

Deputy Editor:
Karen Svensson

Editorial:
Tel: +44 (0) 20 7465 3828
Fax: +44 (0) 20 7465 3675
e-mail: david-j.brown@arup.com

Front cover:
Roof of the Sony Centre, Berlin (pp18-23)
(Photo: Roland Horn, Berlin)

Back cover:
Temporary Exhibition gallery, Walsall Art Gallery (pp34-37)
(Photo: Hélène Binet)

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.


Morley von Sternberg

3

Credit Suisse First Boston: 'Project New World'
Paul Hewes
Edward Russell

Credit Suisse First Boston's rapid expansion at Canary Wharf, London, required the provision of more than double their original floor space. In under two years Arup project-managed the creation, fitting-out, and occupation of over 70 000m² of new-build and refurbished accommodation.


J Willebrand

8

GSW headquarters, Berlin
Nils Clemmetsen
Wolfgang Muller
Chris Trott

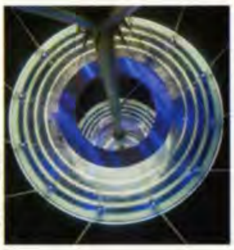
This project comprises a new 22-storey office tower, a refurbished 17-storey office block, and other low-rise buildings. The client, one of Germany's largest providers of social housing, required the buildings to have low energy consumption, and Arup carried out the engineering design to provide this.


Keith Paisley

13

Central Square, Newcastle upon Tyne: Phase 1
Nils Clemmetsen
Andrew Goodfellow
John Loader
Nick Merridew

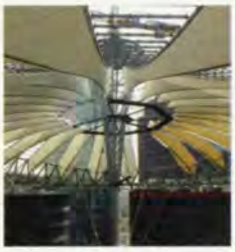
Arup identified this disused 1930s Post Office sorting office as a potential new home for its expanding Newcastle office in north-west UK, and engineered its refurbishment as a high-quality office building. It is hoped that this development will also act as a catalyst for the regeneration of this area of the city.


Arup Associates

16

A beacon for the City of London
Mick Brundle

Signalling the impending creation of Plantation Place - 95 000m² of retail and office space in the City of London - Arup Associates designed this beacon: a column of illuminated translucent glass rings apparently hovering in space.


Markus Schulte

18

Forum Roof, Sony Center, Berlin
Ross Clarke
Bruce Danziger
Markus R Schulte

As the centrepiece of Sony's new European HQ - part of the redevelopment of Potsdamer Platz in Berlin - Arup designed this spectacular hyperbolic cone roof in prestressed fabric, cables, and glass on a 102m x 78m triangulated steel ringbeam, supported 41m above the Forum at seven points from the tops of the surrounding buildings.


Peter Mauss/Esto

24

Alfred Lerner Hall, Columbia University, New York
Bruce Danziger
Matt King
Ashok Raiji

For this new student centre, Arup carried out the mechanical, electrical, public health, lighting, and fire engineering design, as well as the structure and façade engineering for a 30.5m glass wall which encloses and completes the scheme, creating a circulation hub.


Arup

28

Packaging and transporting nuclear materials
Chi-Fung Tso
Patrick Donelan

This article outlines key projects undertaken by Arup in the 20 years the firm has been providing consultancy services to the nuclear industry. These have included design, safety assessment, project planning and project management, risk assessment, and impact and thermal analysis.


Cork Examiner

31

Irish racecourse projects
Seamus Mulherin

Since 1995, Arup's Irish practice has been involved in the redevelopment of several Irish racecourses. This work has included project management, design team leadership, planning, and engineering for enclosures, stands, and tracks.


Colin Jackson

34

Walsall Art Gallery
Katherine Holden
Colin Jackson
Jeff Shaw

Designed and built both to house the historic Garmon Ryan Collection and to provide substantial and flexible Temporary Exhibition spaces and other facilities, the new Walsall Art Gallery in the UK West Midlands has been engineered by Arup to the highest international standards of gallery environment design.

Credit Suisse First Boston: 'Project New World'

Paul Hewes Edward Russell

Introduction

In 1993 CSFB relocated to Canary Wharf[1] in London's Docklands, and occupied $9^1/_2$ floors of One Cabot Square (FC1). Space demands accelerated extremely rapidly with major acquisitions, and by 1994 they had grown to fill the entire 20-storey building. By 1996 further expansion was required, and the previous evolutionary approach could no longer provide sufficient floor space fast enough. CSFB identified that between 1997 and 2000 their space requirement would more than double, from 46 500m^2 to 116 000m^2. The vehicle to satisfy this, 'Project New World' (PNW), was born.

The initial concept was to purchase from Canary Wharf Ltd a new 23 200m^2 building, 20 Columbus Courtyard (B5). This was originally conceived as an independent structure but its construction halted at ground level when Olympia & York, the previous Canary Wharf developer, went into liquidation.

The proximity of the sites presented a unique opportunity to join the two buildings together and create the largest dealing floors in Europe.

Arup Project Management was employed by CSFB in March 1998 to take overall sitewide responsibility for PNW, managing all aspects from design, through construction, and into the final user migration. By December 1999 Arup had delivered approximately 46 500m^2 of new-build and 23 200m^2 of refurbished office space, including two of Europe's largest trading floors, a new 700-seat restaurant, retail and leisure facilities, and conference and auditorium facilities, across three buildings. Managing a consultant team of over 200 professionals, three contractors were used with five separate construction contracts to move over 5000 employees in under two years.

Sitewide responsibilities

Arup handled the following tasks:

- establishing project strategy and procedures
- managing the design and construction teams
- planning and programming - design and procurement
- migration planning
- monitoring and driving progress - client, designers, and contractors
- preparing budgets, tracking expenditure, and forecasting costs, with the quantity surveyor.

Establishing project strategy and procedures

Fig 3 overleaf shows the strategic programme for the three buildings FC-1 (existing), B5 (new-build, attached to FC-1), and B4 (new-build separate structure bridged to B5 on eight floors). A further 7000m^2, One Westferry Circus, was added to the programme late in 1999. All played different, yet critical, parts in the overall success of PNW. Initial strategic decisions included accommodating the full PNW IT requirement into FC-1 to allow all other buildings to come live as quickly as possible.

Managing the design and construction teams

The key organisations are clearly the consultant and design teams from the outset, and subsequently the contracting teams. With a project of this scale, involving so many organisations and individuals, it is critical that interfaces function properly, both formally and inter-personally.

Arup was central to ensuring that this took place; mechanically by having suitable procedures and lines of communication in place and, as importantly, by ensuring that those involved could together identify problems, analyse solutions, and enact resolutions. The core of Arup's role was to 'make it happen'.

Planning and programming - design and procurement

When Arup was appointed, construction was already under way on FC1 and on the shell and core works of B5. One of Arup's first tasks was to prepare a base master programme for all construction activities and move dates across the three buildings. Initially the separate programmes from the two contractors then involved were amalgamated into one document. The overall logic thus revealed identified clashes which needed to be eliminated rapidly.

The decision in July 1998 to add B4 made reworking the whole migration plan necessary. The effect on the construction programme was greater than just adding another building, as construction in the existing building had to be extensively re-programmed to align with the new migration plan. To ensure the programme dates were hit for this extremely fast track project, a client decision schedule was instigated, which was used as a live document to ensure that all the required decisions were made and recorded in a structured manner.

Migration planning

From May 1999 to the end of January 2000, the migration team planned 5000 personnel moves associated with occupation of PNW space; a further 4000 will complete the reorganisation of the vacated space. The initial framework linked real estate lease termination / commencement dates to a clear project critical path.

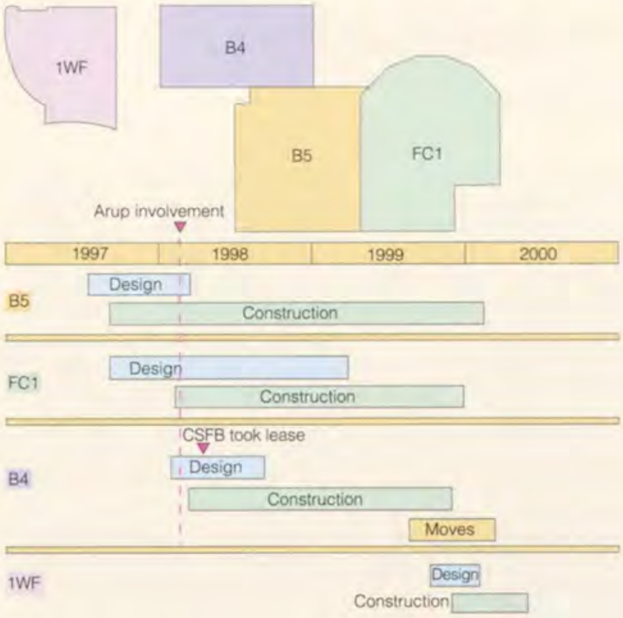
A migration schedule was developed, incorporating constraints like working hours, noise restrictions, and landlord facilities operations with migration logistics and space planning. The migration planners were responsible for integrating the needs of the Bank's 'user groups' with the delivery of space, and regularly met with the business management to ensure that:

- Space planning was consistent with group budgets and expected growth and / or promotions.
- Large groups to be split between floors and moved over several weekends had feasible intermediate business adjacencies.
- The specific IT requirements of each group were fully understood, particularly trading environments.
- Opportunities for business re-organisation, consolidation, or technology refresh were realised.
- Bank standard furniture and office allocation was re-established.
- Groups had clear expectations on relocation timing and target dates for sign-off of space planning layouts and supply of 'names-to-desks' information.
- Administration to do with the space planning was done by the migration planners, allowing the client personnel to concentrate on their core business.
- Problems and queries were handled promptly with appropriate client authorisation.
- The groups and PNW planning team gained confidence in Arup to manage delivery of the space.

Thorough management of change was critical to delivering the new space.

1.
Canary Wharf site plan.

2.
CSFB dealing room on level 3 of building B5.



3 left:
Strategic programme.

By working closely with the IT team, the migration planners were able to agree suitable handover target dates for satellite equipment rooms and communications suites and allow vacated floor areas to be set aside for upgraded cabling works.

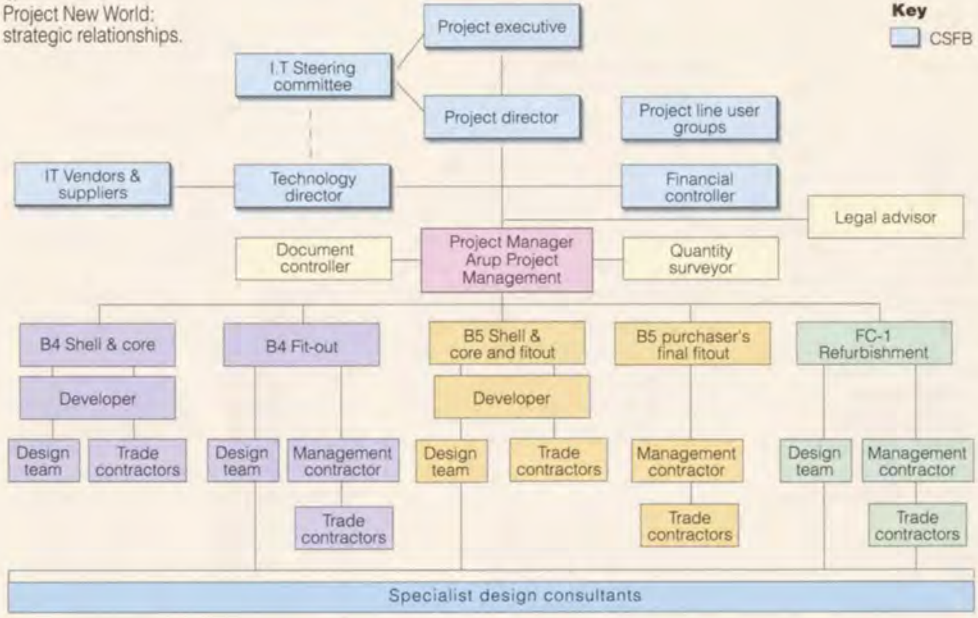
Monitoring and driving progress
Fundamental to achieving such demanding targets was establishing and maintaining momentum. It was critical that all aspects of the project status were known at all times, be they design, or construction progress against programme, or the financial position.

To achieve this, a complex and comprehensive structure of meetings, reviews, and reporting was established, adapted as appropriate for each stage of the project including the following:

- *weekly progress reviews*
  - with consultants during design phase
  - with contractors during procurement and construction phases
- *regime of meetings*
  - client decision-making (weekly)
  - open Items (weekly)
  - 'cost flash' reviews (weekly)
  - sitewide moves and changes (weekly)
  - critical issues (daily)
  - project progress (weekly)
- *reporting structure*
  - consultant and contractor reports to support weekly meetings
  - Arup summary weekly report to client
  - monthly progress and key risks to client
  - percentage progress matrices issued to full team to record the status of the following:
    - consultant drawings
    - trade contractor drawings
    - procurement / off-site manufacture
    - site construction and installation
    - commissioning and certification
    - clearance of defects
    - close out of contractual issues
    - resolution of final accounts.

Fundamental to making these activities serve the project, however, was that they identified and dealt with risks and unforeseen events and enabled the team, as a whole, to achieve a pro-active resolution of slippage against programme in any activity.

4.
Project New World:
strategic relationships.



Starting with the strict 'freeze on move' information, including sign-off by senior management, it was acknowledged that business critical changes and leavers / joiners were inevitable. ('Freeze on move' information defined which and how many client groups and personnel were in specific locations at defined and final dates before the move.) A formal change control process ensured that change did not adversely affect relocation programme.

The control of change during freeze periods relied on the following:

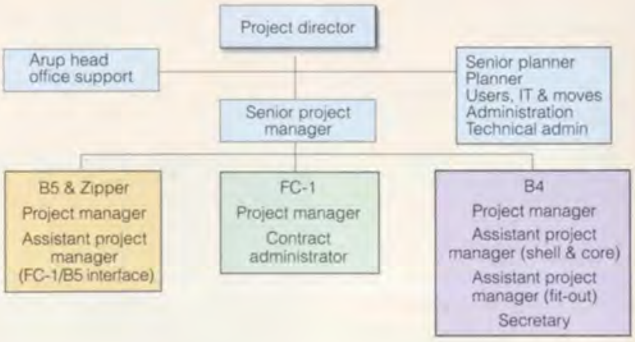
- definition of activities which could take place after hand-over of the floor / area by the fit-out contractor and before occupation
- effective communication to individual users of the location and configuration of their desk in the new space, with appropriate sign-off, to minimise changes
- tracking changes in the existing (move from) spaces as well as planned space.

The migration planners monitored daily progress in design, procurement, and construction, ensuring that any effect on migration-related activities was taken into account. It was recognised that all intermediate key dates relating to staff moves were as important as the end date.

The migration planners monitored client-direct procurement, such as purchase of new furniture, to ensure certainty of delivery / installation within overall migration programme, influenced by:

- decisions on purchase or redeployment of furniture and equipment, particularly long lead procurement items
- the maintenance of an inventory of spare furniture for use as 'swing', allowing time to prepare desks for network 'patching' prior to intensive moves
- the gradual reduction in pre-deployed furniture, increasing activity intensity over migration weekends.

5.
Arup's site-based management team.



6.
West entrance to building B5.

Preparing budgets, tracking expenditure and forecasting costs

Following Arup's appointment, one of the first actions of the team was to appoint a quantity surveyor, as the project had been inherited without formal cost control. Exhaustive interviews were carried out, resulting in the appointment of Northcroft, who soon had a team of over 10 quantity surveyors working on the cost plan. At the weekly 'cost flash' meetings with CSFB, all variations arising during the week were discussed, and each month a detailed cost report was prepared by Northcroft comparing anticipated final costs with the budget.

Detailed cost control on a project of this size and speed is essential, as parts of the design were being carried on during construction and the client needed to make changes throughout the process.

Building services

The nature of the client's business placed extreme demands on all aspects of the buildings, both in technical and environmental terms. This directly impacted on the building services, requiring all aspects to be extraordinarily reliable and sophisticated.

Particularly acute demands were placed on the control systems for PNW with a cutting-edge building management system (BMS) and an electrical monitoring system (EMS) introduced to cover all three buildings; each created different demands and challenges, discussed below, but the same principles applied throughout PNW and standards and specification needed to be entirely consistent.

One Cabot Square (FC-1)

The design team first concentrated on upgrading the infrastructure of the existing building. CSFB, like many large financial services sector clients, place great emphasis on the flexibility and resilience of their engineering systems, as they are essential to the successful operation of the business. A substantial upgrade of the IT system was instigated immediately (including two new IT Suites), as the expanded systems were needed to support the growing building.

All plant was selected on a n+1 basis (every item duplicated) to ensure a high degree of resilience and uninterrupted operation in the event of failure of any item of plant.

A phenomenal amount of work was undertaken in the existing building while it was still occupied, with approximately 250 tonnes of services plant installed on the roof 20 storeys up.

Internal operations were similarly challenging, with risers being inserted throughout the building to contain services and IT.

Mains electrical supplies were provided from two separate substations, together with an autochange over facility enabling the building to be supplied from either source.

The existing backup electrical supplies were enhanced with two additional 1600KVA generators and by four additional 800KVA uninterrupted power supply (UPS) static systems. Again the UPS supply was calculated on an n+1 basis.

20 Columbus Courtyard (B5)

The dealing floors are critical to CSFB's business and to save space, decrease loads and heat output, and to improve the working environment, flat screen technology was introduced.

Extensive testing was carried out on the desks to mimic the real conditions, and the results used to avoid potential problems occurring in the final installation of a notoriously difficult element.

Static switches were used extensively in the electrical services system on a scale not seen previously in the UK, to increase confidence in the reliability of the system and provide greater flexibility during construction and during the subsequent operation of the buildings. These switches allow the essential loads of B5 building to be supported from FC1.

As in FC1, B5 has duplicate electrical supplies as well, together with disaster recovery links to FC1 via the static switches. Full electrical back-up supplies are provided by four generators and a UPS system.

17 Columbus Courtyard (B4)

The high demand for confidence in the system was as critical in B4 as the other buildings and the design, likewise, incorporated a UPS system to protect the entire electrical services of the building, with static switches included to provide additional cover for the IT areas.

7.
Auditorium antechamber on level 7 of building B5.

8.
Auditorium on level 7 of building B5.

Control systems

Controlling complex engineering systems in a series of interconnected buildings is a major task.

A new control centre was constructed in the FC1 building and head end systems for the BMS, EMS, and other monitoring systems were all housed there.

Buildings FC1 and B5

With the knowledge that the two buildings were to become one, initial planning centred on getting the new dealing floors operational at the earliest date. The demand for completion of the dealing floors did not, however, allow sufficient time for IT suites to be constructed in B5, so new IT suites had to be built in FC1 so that they would be operational at the same time as the floor space being completed. The construction of these also required the installation of considerable, new infrastructure services as described above. The two new suites covered an area of more than 2000m^2 and were designed to accommodate over 1000 voice and data cabinets and ancillaries.

'Zipper' construction

The task of joining the new and existing buildings gave the whole team many challenges. Exhaustive surveys of the floor levels of the existing structure were undertaken to ensure that the floor slabs in the two buildings were accurately aligned.

9.
The 'retail snake' on level 5 of building B5.

10.
Restaurant on level 9 of building B5.

This was a complex task during the early design stages when the building was fully occupied, with ceilings and floors intact and the concrete cladding still in place.

During construction, temporary walls were erected in the existing building adjacent to the external wall and the resulting 'zipper zone' was stripped of its fittings and services.

The temporary walls included multiple acoustic and waterproofing layers because, for many months, it formed the acoustic, fire, and thermal barrier between occupied offices and the construction site.

Associated with the cladding removal were substantial enabling works for the engineering team, re-routing existing air intakes and exhausts that had hitherto been connected to louvres in the original façade.

When the new building structure was constructed to within 500mm of the existing building, the cladding was either removed by crane or by breaking into small pieces using portable concrete crushers, working through the night due to the sensitivity of the location and access constraints. Seismic joints were then used to join the two buildings to allow for relative movement, and the 'zipper zone' was fitted out. Finally the temporary wall was removed on each level to reveal the new integrated floor plates. The co-ordination required to manage the construction on both sides of the 'zipper zone' was extensive, and once the temporary wall was removed required further, complex on-site management of both contractors. In all, only 13 months separated signing the agreement between CSFB and Canary Wharf and laying carpet on the first trading level - a remarkable achievement.

Level 5

The existing restaurant was on the fifth floor of FC1, but as it became redundant with the opening of the new one (see below), it was stripped out to make way for building a new shopping mall running between the two buildings. Known as the 'snake' due to its shape, this is now home to the CSFB retail area, vending mall, dry cleaners, travel and foreign exchange centre, post centre, and presentation areas. The 'snake' is fitted out to a high specification, with its full length panelled with Swiss Pear and marble flooring laid throughout.

Level 7

To meet the enormous demand for high quality meeting rooms, the entire seventh floor is dedicated to this use, providing 50 meeting rooms and two auditoria of 100 and 250 capacity each, the larger equipped with full audio-visual and video conference equipment. This whole floor is fitted out to an executive floor standard, with American Walnut, polished plaster, and fabric panels used extensively. All meeting rooms have audio-visual equipment and five were fitted out as specific video conference rooms - known to the project team as the 'Star Wars' rooms!

Level 9

To cater for the substantial increase in the size of the Canary Wharf estate and the growth in numbers, the entire ninth floor of the B5 building is the 700-seat restaurant. The restaurant makes its food preparation a public feature - the so-called 'theatre cooking' - so in addition to a conventional kitchen there are island serveries where chefs prepare high quality food in front of their customers.

The engineering challenge was further complicated by the construction of a glazed roof over the whole of the servery area. Off-site mock-ups were used extensively to ensure that ground-breaking design was turned into reliably functioning construction and to avoid time-consuming and costly remedial works on site.

Building B4

Critical to the overall success of Project New World was the delivery on programme of 17 Columbus Courtyard (B4), an 18 600 m^2 new office building - the third and final element of PNW. To achieve the programme demands, a strategy was required which undertook the fit-out of B4 in a record-breaking 19 weeks. The strategy was based on overlapping the shell-and-core works with the fit-out and subsequent migration activities, whilst providing a four-week contingency. Various measures were used to ensure certainty of delivery, including complex procurement and construction logistics, continuous and responsive risk and value management, and a package of targeted incentives.

The shell-and-core construction of B4 commenced in mid-1998 with completion targeted for 1 August 1999. CSFB needed the fit-out works to be complete before Christmas 1999 to enable the first users to take occupation in mid-January 2000. This only left a clear period of 19 weeks for the fit-out of the high-quality front-of-house office space, including all IT provision, a library and a coffee bar. It was apparent from the outset that specific, uncommon measures would be required to ensure that these completion dates were met. The key strategic measures needed are discussed as follows:

Shell-and-core modification and enhancements

Due to the limited fit-out period, specific works and fit-out enabling activities were added to the shell-and-core scope. These included:

- bridge links at ground to seventh floors (1860m^2)
- entrance hall reconfiguration
- 10-storey spiral staircase
- fit-out enabling builders work (additional fit-out IT risers, structural openings in beams for horizontal services, etc)
- services modifications to provide considerably upgraded provision and n+1 redundancy on all business critical systems.

Overlap with shell-and-core

A critical part of the start-up strategy was to negotiate early access to the site before shell-and-core practical completion to enable the set-up and commencement of preparatory fit-out activities. The purpose of this was twofold:

- to allow the fit-out activities to be fully effective from Day 1 of the fit-out site period
- to mitigate against the risk of shell-and-core over-run.

It was important however, that any overlap fit-out works did not disrupt completion of the shell-and-core.

Early involvement of contractors

Critical to success was to involve both management and trade contractors at as early stages as appropriate. To achieve this the following actions were taken:

- The management contractor was employed as a construction consultant during the consultant detail design stage.
- Tendering management contractors were encouraged to form an alliance with the lead services trade contractor.
- The management contractor was formally appointed to maximise the time available during the procurement phase to develop logistics plans, early involvement of trade contractors, and pre-site manufacture.
- The lead and other key trade contractors were appointed on a two-stage basis to allow the early commencement of fully co-ordinated installation drawings.
- Trade contractors were encouraged at the tender stage to ring-fence resources, both personnel and material, to ensure certainty of delivery.
- A pre-construction project team office was established, accommodating the full management contractor's team, the designers for the key trade contractors, and the commissioning management team.
- A requirement of the co-ordinated trade contractor design was that modularisation and prefabrication was to be identified and incorporated wherever possible to reduce the complexity of the site works and the time involvement on site. Similar principles were also applied to commissioning, witnessing and certification.

11.
Coffee bar in building B4.

Prototype

Due to the limited period available on site, it was critical that all fit-out elements were physically fully co-ordinated and that fit on site was achieved in the most efficient manner possible. To generate confidence in this, a full-size prototype was erected in an off-site warehouse, demonstrating one structural bay of the office space (cellular and open-plan) and core extensions (ancillary and IT rooms), and including the full low- and high-level services. The prototype also acted as a test bed for re-engineering specific details to improve co-ordination, fit, buildability, and finished quality. It was constructed by the actual trade contractors to be used on the project and thereby established the learning curve before site start. It was inspected by the consultant team to establish the required quality level, hence becoming a complete dry run of the proposed final construction process and sequence.

Early manufacture and off-site storage

Due to the limited period on site, it was vital that before start on site there was certainty of delivery of all required materials (similar to the ring-fencing of labour to provide certainty of availability). To achieve this, a warehouse was rented from three months before site start until completion, and used to store most of the fit-out materials until needed. Materials were then delivered from the warehouse to the on-floor point of installation by a dedicated logistics crew in project-dedicated trucks.

This gave complete control over timing of deliveries, ensuring only appropriate elements and quantities were delivered and avoiding congestion in delivery and on site.

Formation of the team

Central to the project success was buy-in and ownership from all parties to the project - from the client through consultants to contractors. Many activities thus needed to be restructured to incorporate and empower members of the team not normally associated with a specific activity or stage.

This took place at design yet continued through construction to overcome unforeseen eventualities. The project commenced with a full team brain-storming, including involvement from the client, consultants, and management contractor. This analysed the programming, design, and logistical issues; confirmed key objectives; identified risk areas;and provided strategic solutions. These issues and their potential resolution formed much of the strategy for the remainder of the project.

It was only by building and continually reinforcing this total team approach, including regular risk and value management sessions, that it was possible to achieve the required goals.

Site logistics and procedures

The overriding principle was that non-productive down-time needed to be eliminated and that lessons could be learnt from the client's own environment of n+1 resilience on all critical systems. The key areas targeted and methods chosen were site access, vertical transportation, and building management.

Acceleration of IT areas

To guarantee the IT delivery, the construction and fitting-out of the IT areas (suite, two satellite equipment rooms per floor, and cabling routes to other buildings) was targeted as part of the early access works and given an early possession date of mid-November, with guaranteed stable power and cooling - both essential for the follow-on IT works. This was actually bettered by three weeks, giving an increased buffer for construction of the IT network.

Incentives

To reinforce and give greater confidence in the success of the above measures, a package of incentives was targeted at all levels, from management and trade contractor organisations to individuals on site. it covered final account settlement, achievement of target practical completion and partial possession dates, weekly awards for outstanding performance from trade contractors and individuals, subsidised canteen, and improved welfare facilities.

Conclusion

These two intensive years have seen Arup Project Management lead a team of over 200 consultants, with three major contractors, and using innumerable trade contractors, to create a London estate of approximately 116 000m^2, accommodating over 6000 people.

This was achieved in the period leading up to the Millennium, with inflationary pressures on scarce labour and material resources, but nonetheless ahead of programme and within budget. Added complications accommodated included EMU convergence at the end of 1998 and Y2K at the end of 1999. Incorporating complex phasing of construction works in and around live buildings, over 8000 personnel moves were handled whilst ensuring that the client continued to operate in a 'business as usual' environment - that of the demanding, high speed, and successful banking world.

Reference

(1) MUDD, I *et al.* Canary Wharf. *The Arup Journal, 27*(2), pp10-14, Summer 1992.

Credits

Client:
Credit Suisse First Boston Ltd.

Project manager:
Arup Chris Ambrose, Neil Barbour, Sonia Barker, Andrea Blackie, Greg Blouin, Ciaran Brady, Jonathan Brecknell, Jane Bushaway, Alison Butcher, Angela Crawford, Hugh Dullage, Keith Farley, Paul Hewes, Peter Karabin, Joanna Kennedy, Dan Lonergan, David Loosemore, David Maxwell, Adrian Morey, Bill Mountakis, Paulette Nicholls, Edward Russell, Demetri Serghiou, Karla Snook, Louise Unicomb, Clive Wilson, Chris Wood

Fit-out architect (FC1, B5, B4):
Gensler

Shell-and-core architect (B5):
Skidmore Owings and Merrill

Structural engineer (B4):
Cantor Seinuk

Mechanical and electrical engineer:
Hilson Moran Partnership

Quantity surveyor:
Northcroft

Certification engineers:
Waterman Gore

Legal advisor:
Freshfields

Specialist lighting designers:
Lighting Design International

Restaurant designer:
Parker Roberts Design Partnership

Catering designer:
Cini-Little

Acoustic engineers:
Applied Acoustic Design

FC1 contractor:
Interior Plc

B5 shell-and-core and fit-out contractor:
Canary Wharf Contractors Ltd.

B4 shell-and-core contractor:
Canary Wharf Contractors Ltd.

B4 fit-out contractor:
Bovis Lend Lease

Illustrations:
1: Jonothan Carver
3-5: Emine Tolga
2, 6-12: Morley Von Steinberg/
Credit Suisse First Boston

12.
The complete Project New World development from West India Quay.

GSW headquarters, Berlin

Nils Clemmetsen
Wolfgang Muller
Chris Trott

Introduction

The new headquarters building for Gemeinnützige Siedlungs und Wohnungsbaugesellschaft (GSW), one of the largest providers of social housing in Berlin, stands in the centre of the city, very close to the line of the Berlin Wall and where Checkpoint Charlie used to be. In all, there are five distinct buildings above ground: an existing 17-storey office block built in 1961, the new 22-storey tower, two 10m tall low blocks, and a three-storey drum - the 'Pillbox' - perched over one of the latter. These are joined into one complex by a single-storey basement, covering virtually the whole site, which gives access to a deep sub-basement containing a mechanical parking system for 228 cars.

Project history

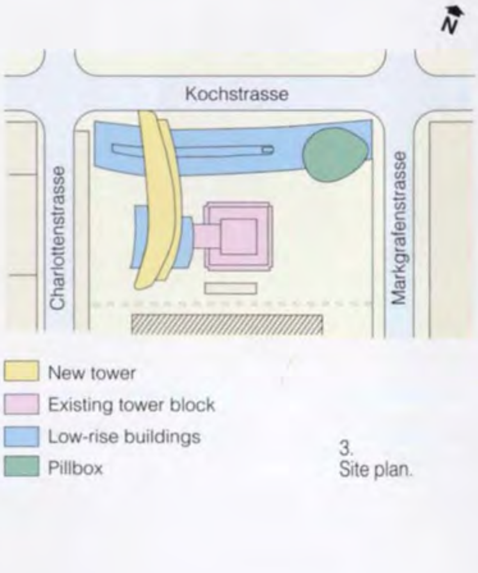
In the late 1980s, before the Wall came down, GSW needed additional office space and decided to develop further on their site with a 22m high building surrounding the existing one.

The planning authorities rejected this and subsequently GSW held a design competition with six invited architects in 1990/91, the brief being to incorporate the existing building into the new development and to create a link between old and new.

The jury unanimously chose the design by Matthias Sauerbruch and Louisa Hutton, a practice then based in London, who entered the competition with Arup support. Unlike other competitors' low-rise designs, they proposed one based around a slender 22-storey tower linked to the existing tower. An important design aspect was that the building would have low energy consumption, a key component being the 'thermal flue' on the west-facing elevation.

1.
The new GSW tower from the west.

2.
The new GSW tower from the east with the refurbished building in the foreground and the 'Pillbox' to the right.



3.
Site plan.

The scheme design was prepared in London in 1992 with Arup providing multidisciplinary engineering design services. In early 1993 the architects moved to Berlin to continue work on the project, with Arup GmbH as engineer. The changing economic climate made the client review the project following completion of the detailed design, and they decided that substantial parts of the tower should be rented out.

This required greater flexibility in layout and led to a revision of the building concept, which had significant impact on both the environmental and structural aspects of the new tower's design. Arup GmbH joined with a local consultant, IGHmbH, to carry out the remaining work on the project. The revised detailed design was produced in early 1995, closely followed by start of construction on the sub-basement for the mechanical parking system.

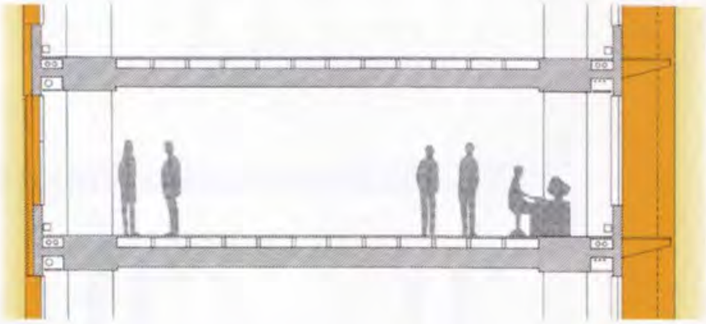
Building services principles

The building is naturally ventilated for around 70% of the year - only possible for a 22-storey building if its basic design significantly reduces the speed of the wind through open windows. The existing 17-storey building suffered from excessive draughts when the windows were open, and overheating when they were closed. The proposed building configuration sought to improve this, creating an environmentally friendly new tower. The key driver in the choice of its location, form, and orientation was to form a wind lea. Locating the new tower west of the existing one shelters the latter from the prevailing wind - improving the prospects for opening windows, and shading it from the afternoon sun.

Natural ventilation for the new tower

Initially there was a double strategy for reducing draughts in the rooms. The principal solution was to protect all openable windows on the west façade with a single-glazed weather screen suspended 1m from the internal double-glazed façade, which, acting together as a buffer zone, was the main protection against heat loss. This arrangement became known as the 'thermal flue', inducing cross-ventilation through the building when it is warm and if winds are weak.

Arup's analysis of the natural ventilation system is described in the panel opposite.



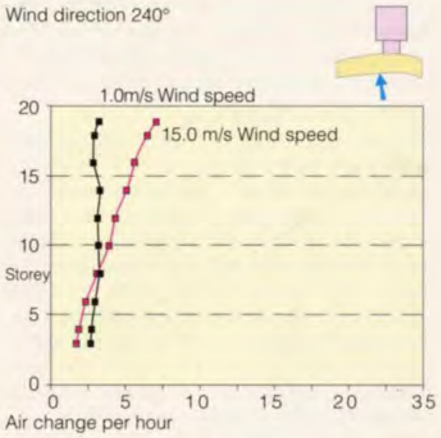
5.
Buffer zones.

Natural ventilation analysis

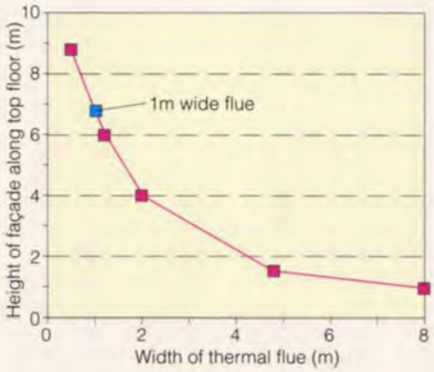
To ensure that the natural ventilation system works as well as possible, Arup carried out extensive analysis using in-house software to size the necessary passive ventilation elements.

This included determining the optimum thermal flue depth (1.0m was chosen) and its height to the highest discharge point. The size and control of the flue's top and base dampers were also studied extensively.

The airflow paths and ventilation openings through the east and west façade windows were analysed to ensure reasonable control of cross-ventilation of the adjacent offices, and this analysis was informed by a series of wind tunnel tests to determine the required pressure coefficients around the building for varying wind directions and strengths. As part of the façade package, a model test was undertaken on the windows to ensure that their pressure and flow characteristics as they were opened met the performance parameters we specified.

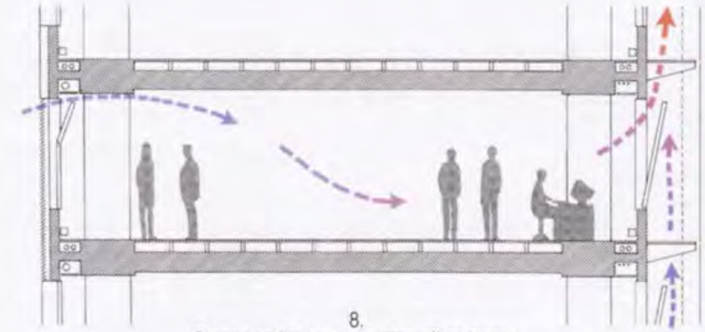


6.
Air changes per hour in offices during natural ventilation.

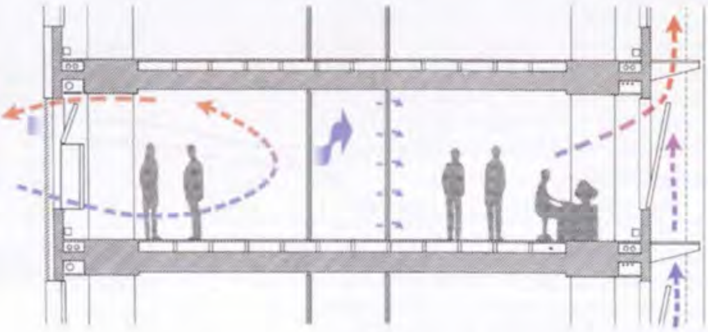


7.
Width of thermal façade to avoid backflow through offices.

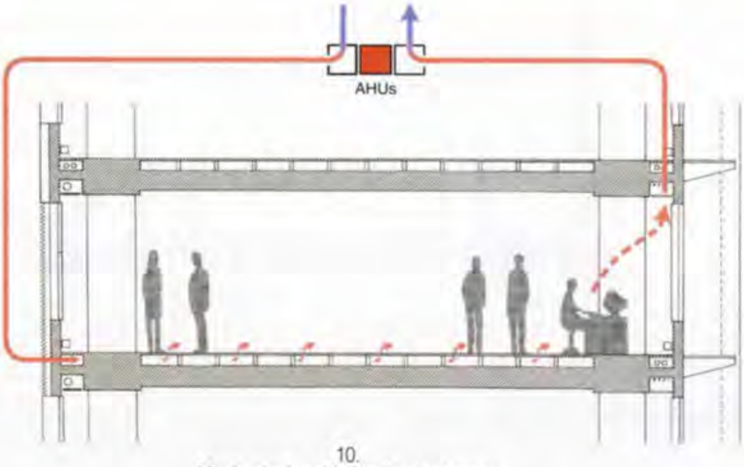
4.
View from the roof of the tower with the top of the thermal flue in the foreground.



8.
Cross-ventilation: open plan office layout.



9.
Cross-ventilation: central corridor office layout.



10.
Mechanical ventilation: heat recovery.

Whether wind direction is westerly or easterly (the predominant Berlin wind directions), the thermal flue reduces wind-induced air flow through the building by either acting directly as a barrier to westerly winds, or by constricting the air flow through the building from the east. Air flow into the base of the flue and out of the top is regulated by dampers controlled by the Building Management System (BMS).

The air flow through the building can be controlled by the occupants (or the BMS at their discretion) during occupied hours, and by the BMS out of occupied hours.

The second key element was a continuous corridor along the east façade, giving access to all occupied zones to the west. This would have allowed relatively simple windows to be used in the east façade, but the strategy had to be changed when a requirement for the possibility of offices along both façades with a central corridor between was introduced. To improve comfort for occupants now sitting immediately adjacent to the east façade, it was redesigned as a buffer zone against extremes of weather by introducing a triple-glazed system with mid-pane blinds (openable only for cleaning access). This system included for each 3.6m office module a vertical window element containing a high-level hopper - normally used for cross-ventilation on open-plan floors - and a conventional height window openable to provide single-sided ventilation for rooms along the east façade. Both windows have an external fixed louvre for weather protection to the inner windows and to provide a safe opening, given the height of the building.

User interface

Users can choose natural or mechanical ventilation (with limited cooling in hot weather), and whether to have shading devices open or closed.

It was felt desirable to give the occupants as much control over their own environment as sensible, plus simple guidance on the energy benefits of natural ventilation. The design team therefore decided to put the necessary controls and information on the window transom in each office module. These comprise green and red lights which, when illuminated, indicate whether natural or mechanical ventilation is recommended by the BMS, and simple rocker switches to close and open the windows and shades. The occupants can choose either, irrespective of the BMS recommendation.

Layout flexibility

The new tower was designed to offer flexibility in layout, including open-plan, cellular offices either side of a central corridor and a mixture of hybrid cellular and open-plan layouts. Perhaps the most demanding arrangement was the full cellular office area, as it stops air flow through the east office zone into the west offices.

To overcome this, larger opening windows and panels were incorporated into the façade near the tower cores, the largest recessed into shadow gap features separating the new and existing tower buildings.

These allow air directly into the corridor zones, and from thence into the western half of the plan. Where there are offices on this side of the building the air passes through specially developed acoustically dampened panels beside each door.

Mechanical ventilation

This was incorporated for comfort during seasonal weather extremes when, for most normal office uses, the windows need to be closed. The building is well insulated; the glazing system has an average U value of 1.6W/m^{2}K, and the external walls and roof 0.3W/m^{2}K and 0.25W/m^{2}K respectively. This does not include the external glazing to the west façade, so in effect the U value is better still. The main air-handling plant is in a two-storey plantroom at the 22nd floor (just below the roof). The central plant has variable air volume control to respond to the ventilation needs of the floor zones. Air is supplied from the floor via swirl diffusers recessed into a raised screed system which itself acts as a plenum. The floor plenum is divided into three zones, which in turn are fed with air from local risers, allowing all floors to be mechanically or naturally ventilated, with up to three tenant zones per floor. Mechanical ventilation is initiated by the BMS, although occupants can select individual zones within a floor in either mechanical or natural ventilation mode by a simple wall-mounted zone controller.

Air is returned to the central plantroom via risers for heat recovery in winter. Perimeter radiators are provided with individual thermostatic radiator valves, sized for a -14°C winter condition. Because the client has quite high internal equipment loads, and because tenants had to be offered reasonable equipment loads too, the building has a limited comfort cooling system.

The system is designed to 'peak lop', ie provide maximum internal temperatures of about 27°C at external temperatures of 32°C. In keeping with the environmentally friendly design, no refrigeration systems are used. Instead, cooling is based on spray coolers and desiccant thermal wheels, the latter regenerated using the district heating supply which in winter provides the heat source for the air handlers and radiators.

The heat required to dry the desiccant thermal wheels in summer is essentially a by-product of electricity generation for the local grid, and as such adds very little CO_2 to the atmosphere that would not already be produced for electricity.

Integration

The building relies on the fabric's ability to store heat to reduce the capacity and energy use of the plant. Because there is negligible capacity in the façades, heat is stored in the ceiling and floor by using exposed concrete soffits and a cementitious voided screed system. Services distribution around the floors was therefore either integrated into the slab soffit or into the voided screed.

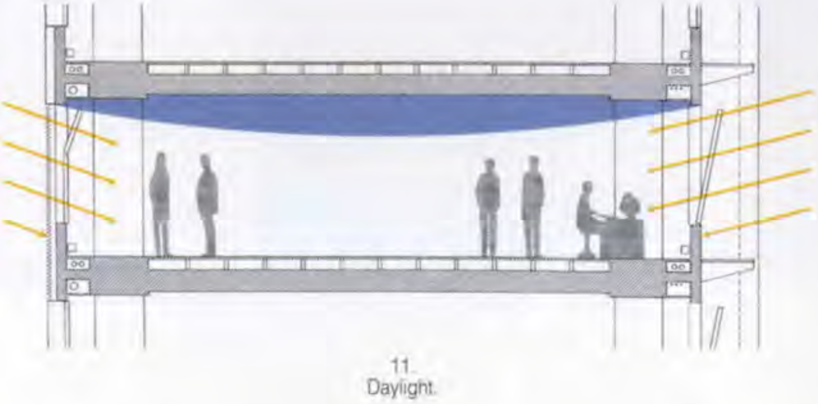
The principal ceiling level services are lighting, sprinklers, and fire alarms, distributed from the cores in a narrow removable strip (450mm) along the façades, and then transversely across the office zones in concrete recesses. These house the low energy fluorescent luminaires, cables, range pipes, and sprinkler heads. The ceiling strip also provides a return air path allowing the mechanical ventilation to return to the cores.

At floor level, as well as the swirl diffusers, distribution systems include stub ducts carrying air from core risers into the three floor zones, structured cabling for communications and data and its containment, and power distribution and its containment. Distribution along the length of the building is below raised floor elements that follow a notional corridor zone.

Transverse distribution is below the voided screed to the recessed circular floor outlet boxes.

Daylight

The new tower is a maximum 11m wide, with glazing from a low cill level (approximately 600mm above the floor), to slab soffit level. This provides extremely good daylight to the office floors from both sides, and much reduces the need for artificial lighting even when the shading systems are closed, because good daylight is always available from at least one façade. The west façade shading is a series of vertically pivoting and sliding panes suspended within the thermal flue, containing 18% perforations. This may seem a low figure, but from within the building it still produces a bright environment with spectacular views across Berlin.



11.
Daylight.

Lighting

The lighting in the office spaces consists of linear fluorescent fittings with specular 60° cut-off louvres. The light fittings are recessed into the slots in the exposed concrete soffit. The offices, which are primarily daylit, are illuminated to 300lux by the artificial lighting. The lighting control system is based on the European Instabus (EIB) system which was primarily adopted to provide flexibility and to enable room layouts to be changed without rewiring.

The row of light fittings adjacent to the windows is automatically switched off by photocells within the façade to encourage the use of daylight. The remaining lighting is manually switched in groups. Occupants can also override the automated daylight linked switching.

Medium and low voltage distribution

The central plant and areas occupied by GSW are supplied from a private substation connected to the local medium voltage ring main. Two 630kVA (10kV/400V) cast resin transformers are linked by a buscoupler to provide a higher degree of security. GSW occupy the lower floors of the tower while the upper floors and low rise buildings are designated as tenancies. As the resale of electricity to tenants is not permitted, the tenant areas are supplied at low voltage from a separate substation within the site, operated by the local electricity supply authority BEWAG. Meter rooms are located in the basement for the low rise buildings and on the seventh floor of the tower.

Standby power

A 400kVA standby generator is located on the roof of the existing tower block which supplies the firefighting lift, passenger lifts (which sequentially return to the ground floor in the event of a power failure), fire suppression, smoke extract system, and emergency lighting. The changeover contactors are located adjacent to the main LV distribution board in the basement.

Lifts

The main lift core is between the existing building and the new tower building, and can be used by the occupants of both.

Six lifts in all are arranged as two groups of three facing each other. The first group serves all levels from the ground floor to level 20.

12.
Linear fluorescent fittings provide artificial lighting for the offices.

The first lift in this group, designed as a firefighting lift, is located in a separate shaft and additionally serving the basement and the plantrooms at level 21. The firefighting lift is rated at 2000kg, while the other two in this group are rated at 750kg. The remaining three lifts only serve the floors from ground to level 16 and are rated at 1250kg. All lifts travel at a speed of 2.5m/s.

The six lifts operate as a single group, and to 'manage' passenger movements efficiently there are two call buttons on each floor to enable users to select which part of the building they wish to travel to: ie G-16th or the 17th-20th floors.

Structure

The tower

The new and old towers are linked for users at each floor. This aspect of the design fixed the floor-to-floor height of the new building to that of the existing one - relatively low at 3.325m. To achieve an acceptable floor-to-ceiling height the services and the structure were integrated as described in the panel below.

The architectural concept was to separate the tower from the low buildings by having its floors span over the large entrance hall void and cantilever out at either end. However, the spans were too great for ordinary reinforced concrete beams within the available depth, so the competition scheme design had the eastern half of the building supported by a vierendeel wall in steel sections; the columns on the western side were to be supported by a truss at third and fourth floors.

As a result of changes to allow offices along both the façades, the vierendeel wall could not be accommodated and columns were required on both sides of the building. A truss was designed at roof level from which hanging columns would be suspended to provide the necessary intermediate support to the floors. Two reinforced concrete beams spanned between the columns along the length of the building, with the floor slab spanning between them. At tender stage, the chosen contractor offered cost savings in exchange for several design modifications, which allowed construction to be simplified. Prestressed concrete edge beams with an upstand into the voided screed meant that the floors could span the distances required without support from the truss at roof level.

This modification was adopted once it was clear that restrictions on service routing and ventilation imposed by the additional upstand beam were acceptable. The increase in edge beam depth was made at the expense of considerable complexity, as the prestressing cables had to co-ordinate with many ducts passing through the beam. Also, high quality control was required as the top surface of the beam formed the finished floor level.

The architect wanted an exposed concrete finish to the columns, but to minimise their size they were designed using steel sections encased in concrete. A further refinement to reduce the columns' visual bulk was to make the shape of the concrete encasement follow that of the H-shaped steel section.

Integrated services and structure in the high-rise floors

The floor system adopted integrates services and structure to minimise the depth, thus gaining the maximum clear height given the horizontal constraints imposed by the existing building.

Slabs span across the building onto beams, themselves spanning between columns set in from the façade. This opens up a continuous space along the edge of the building for return air to be collected.

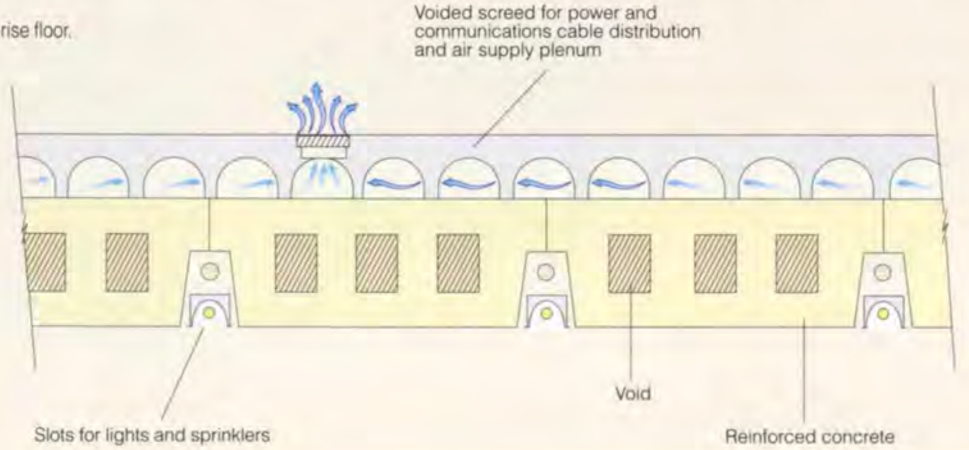
Lights and sprinklers are recessed into 200mm high slots between the precast hollow rib elements which are 1.8m wide between the beams.

Conduits were cast into the beams to route the services to the slots, the complexity of which was increased by the architectural requirement to achieve soffit continuity on possible corridor partition lines.

The maximum span of the slab is 9m, with a depth of 350mm chosen to minimise deflections. To reduce self-weight of the structure, voids were introduced, to be formed around prefabricated reinforcement cages with polystyrene formers wired in place. However the contractor chose to adopt precast concrete slabs to achieve the desired effect.

The voids were generally sealed, though in some locations ducts were cast in to provide a route for the return air from the west façade. A 165mm deep, voided screed distributes the air and electrical services around the floor.

13.
Cross-section through high-rise floor.



14.
Lateral analysis model.

15.
Dynamic analysis output.

Lateral stability

Two reinforced concrete cores give the tower stability. The south core contains three lifts, toilets, and a service riser, the north an escape stair and a service riser. The south core's shape changes below the third floor as one of the car park entries had to pass through it at ground level, but this was compensated by introducing other walls to maintain stiffness and strength at this level. As the cores are relatively slender, the main air risers are outside them to avoid large holes through core walls, reducing their stiffness. Even so, wall thicknesses up to 600mm had to be adopted. Due to the shape of the building and the location of the cores, the south core carries the majority of the windloading, which was calculated according to the Frankfurt design guide for high-rise buildings. This required a dynamic analysis of the building using the program ETABS. In accordance with the design guide, amplification of the wind loading was required due to the low natural frequency of the building structure.

The two towers are structurally independent and allowances for movement between them were required. The main elements affected were the façades, the floors, and the services at the interface.

Low building and 'Pillbox'

The relatively simple-looking low-rise building facing Charlottenstrasse and the Pillbox has hidden structural complexities. Its reinforced concrete walls at first and second floors to the façades, and forming the central corridor, are in turn supported by circular columns in the ground floor. The façade walls are cantilevered out beyond the columns. The columns approaching the Kochstrasse entrance are set increasingly far back from the face of the building above, resulting in the façade wall having to act as a deep beam to span the gap created.

The Pillbox, a three-storey drum which cantilevers over the low-rise building at its eastern end, is supported only by a central reinforced concrete core, from which balanced cantilever steel beams project out to pick up hanging columns supporting the floor edges. This was necessary to create the sense of the drum 'hovering'.

Below-ground structures

Most of the vertical structure in the basement consists of reinforced concrete walls to maximise the number of parking spaces. A mechanical parking system was introduced to increase the number of spaces available, and this required the construction of a sub-basement 16m down below basement level. Diaphragm walls were used, with an intermediate slab for horizontal support.

Ground conditions are highly variable, with layers of sand and glacial till - the latter higher on the east side than the west. In addition, on the west side of the site under the tower, there is a local lens of peat and chalk beneath the south core, necessitating piled foundations under the southern half of the high-rise building. Its northern half is supported by a raft foundation bearing onto sand.

The settlement analysis that Arup carried out predicted that differential settlement along the length of the building would be less with this foundation arrangement than if the whole building was piled. The existing tower was founded on a raft beneath a single-storey basement. Due to the new basement's greater depth, dictated by external ground levels and the deeper foundation slab required, excavation extended below the existing foundations. This required underpinning.

Due to the load imposed by the new high-rise building, it was predicted that differential settlement would cause the existing building to lean towards it. A system of monitoring was installed around the latter to follow the effect of the surrounding construction on it, whilst a grout injection system was installed beneath to enable it to be raised back to vertical.

Here, as in the rest of Berlin, the groundwater level is about 3m below ground level. To construct the basement, the groundwater level was temporarily lowered by dewatering.

Final design and construction information

A proof engineer was nominated by the local authority to approve the design, a process of rigorously checking calculations and reinforcement drawings. He also made site inspections to check the reinforcement prior to the concrete being poured. Due to the fast track nature of the project and the state of the construction industry in Berlin, the calculations were checked at the same time as the reinforcement drawings (it is more usual for calculations to be approved first).

For this project Arup GmbH provided full construction information, including 1:50 formwork drawings to German standards.

The level of information that has to be provided is such that no further calculations should be necessary for constructing the required formwork.

Conclusion

It is early days in the performance of the building, but so far it has performed well in comparison with the design predictions. How it performs is heavily reliant on users, and there may well be differences between the areas occupied by GSW and by the tenants. At the time of writing it is not yet fully occupied. Parts of the lower buildings have been occupied by GSW since November 1997, with the new tower open since September 1999.

In particular, the passive elements of the building have performed well since then, and will continue to improve as the GSW employees receive more training in its use.

The project has been selected to be included as an off-site exhibit for Expo 2000 in Hannover.

Credits

Client:
Gemeinnützige Siedlungs und Wohnungsbaugesellschaft mbH, Berlin

Architect:
Sauerbruch Hutton Architekten

Engineering design:
Arup Andrew Allsop, Sara Anderson, David Bowden, John Brazier, Volker Buscher, Lee Carter, Guy Channer, Adam Chodorowski, John Clayton, Nils Clemmetsen, Sarah Clemmetsen, Chris Clifford, Pat Clowry, Brian Cody, Tim Cromack, Helen Dauris, Paul Drayton, Alex Emanuel, Alan Foster, James Fraser, Ian Gardner, David Glover, Ken Goldup, Robin Hall, Carsten Hein, Andrew Ho, Michael Holmes, Petra Horn, Heike Hörz, Nick Howard, Lucy Jack, Stephen Jolly, Christian Kleber, Geoff Lavender, Keith Lay, Leroy Le Lacheur, David Lee, David Lister, Matthew Lovell, Christopher McCormack, Wolfgang Muller, Hayden Nuttall, Gerry O'Brien, Christoph Odenbreit, Ian Ong, Fred Parsons, Nicos Peonides, John Pilkington, Howard Porter, David Puller, Michael Schmidt, Peter Schuft, Rosie Schwab, Ian Smith, Russell Tanner, Gary Thomas, Ian D Thompson, Steve Thompson, Chris Trott, Laurence Vye, Terry Wanstall, Peter Warburton, Patrick Wheatley

Environmental engineering construction information and site supervision:
ARGE IGH mbH, Berlin (with Arup)

Structural engineering construction information and site supervision:
ARGE IGH mbH, Berlin (with Arup)

Project management:
Harms & Partner

Quantities / site supervision:
Harms & Partner

Façade engineering:
Emmer, Pfenninger + Partner

Geotechnical engineering:
Prof Müller-Kirchenbauer + Partner GmbH

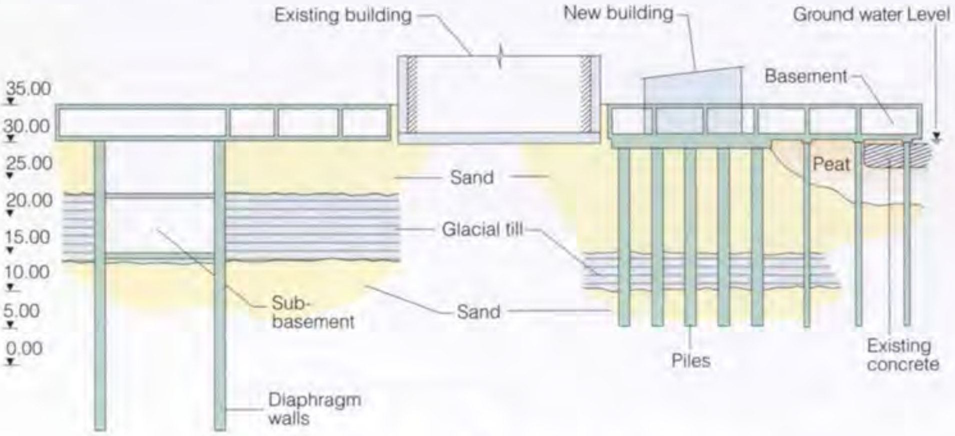
Prüfingenieur:
Dr.-Ing. H Franke

Acoustic consultant:
Akustik-ingenieurbüro Moll

Landscape architect:
STrauma

Main contractor:
ARGE Züblin with Bilfinger & Berger

Illustrations:
1, 2: J Willebrand
3, 6, 7, 13, 16: Emine Tolga
4: Nils Clemmetsen
5, 8-11: Sauerbruch Hutton Architekten
12: Annette Kisling
14, 15: Arup



16.
East-west section through site showing substructures and ground conditions.

Central Square, Newcastle upon Tyne: Phase 1

Nils Clemmetsen Andrew Goodfellow John Loader Nick Merridew

Introduction

For some time Arup has sought a new location for its Newcastle office. The existing premises were outgrown, with too many disadvantages to warrant the upheaval of a major refurbishment. However, Newcastle has lacked quality - but economical - accommodation on large floor plates.

Few developers have recently built speculatively, and many potential tenants have been put off by the delay of around two years between committing and moving in.

Central Square was an opportunity to work with a visionary developer, giving a new lease of life to a redundant 1930s Post Office building, and then moving in as a tenant. Its location just south of Central Station in a neglected part of Newcastle (truly 'the wrong side of the tracks') gives the chance to catalyse urban regeneration by setting standards for surrounding development.

As well as recycling a structure that would have been expensive to demolish and rebuild, the development is particularly 'green' in its location next to the mainline station and interchange with the metro and bus services - another attraction to Arup as a potential tenant.

The firm's Leeds office had previously worked with Carey Jones, the architect, on its own premises and knew of Newcastle's need for a new location; their enthusiastic approach carried conviction. Arup then convinced the future client, Parabola Estates, not only that it would be a good tenant, but that he needed to look no further for his engineers. Newcastle-based Gardiner and Theobald completed the design team as quantity surveyor.

Parabola Estates, who had not previously undertaken a development of this size, was persuaded that Sir Robert McAlpine should be brought in early to help develop the concept within the client's development budget and to the required standards and timescale. So with the team in place, design commenced in August 1998, with a target completion date of spring 2000.

History

Newcastle Royal Mail Sorting Office was constructed in 1935, with four storeys plus a basement and a sub-basement from which a tunnel connects to the Central Station, with lifts from the tunnel to the platforms. The Post Office was closed in 1995 and the building remained unused until redevelopment began. Facing onto Forth Street, to the north of the main building, was a single-storey garage, built earlier.

The brief

Parabola Estates had a very clear idea of what they wanted to create. After visiting many buildings in Europe and North America the following essential requirements formed the basis of Arup's brief:

- to construct an outstanding office building, providing the best possible environment for prospective tenants to assist them in running their businesses profitably
- to design an environmentally-friendly building
- to deliver the building at a price that enables high-value lettings to be offered
- to create a landmark building of exceptional quality.

The scheme

The refurbished building provides four floors of office space, each c1400m^2 (7000m^2 total), wrapped around the large central atrium area to form a large U. The existing 4.7m floor-to-floor height was reduced to 3.2m headroom below the structural beams by introducing a 600mm raised floor and service void. The ground floor was subdivided into smaller units and a 100-person conference facility, with a speciality coffee bar for tenants' exclusive use spilling into the atrium on the ground floor - complete with water feature and trees. The basement was converted into 30 car parking spaces and an archive store, with ramp access from the main road on the north side. Finally the central plant was put in the sub-basement in a series of plantrooms. The client budget for the total refurbishment was set at £560/m^2.

Externally, the old garage was demolished, and the main entrance area with its feature glass tower transformed by a mixture of hard and soft landscaping into a series of circular spaces leading towards the entrance and the landmark sculpture 'Vulcan'.

A key characteristic of the refurbished building is the extent to which the original building form and shape contributes to the light and airy feel of the large office floor plates. The large retained window openings have been replaced with steel-framed double-glazed units with Suncool low emission glass to reduce solar gain.

The refurbishment has transformed the building into a spectacular modern office with large, open, flexible floorplates, emphasising levels of quality both internally and externally that have not previously been seen in the city centre.

Staff survey

The client invited a research company (RDA) to survey Arup staff in the existing office to assist in understanding what constitutes a good office-working environment. The staff were asked a series of questions relating to their environment, and then to focus on the top seven most important features. A clear order of priority emerged:

1 effective 'air-conditioning' and ventilation

2 an effective heating system with temperature control

3 suitable lighting for the work you do

4 a good computer network

5 ease of access by public transport

6 the arrangement of one's own work space

7 the internal layout and circulation of the office.

During this survey it was suggested that a BREEAM (Building Research Establishment Environmental Assessment Method) assessment be undertaken to demonstrate to potential tenants, including Arup's own staff, the commitment of the client and design team to providing a good working environment and a building environmentally conscious in its design. The survey will be repeated to compare perceptions before and after the move.

1 top:
External view of development from Forth Street.

2.
The impressive atrium contains commissioned works of art and houses the 'Quadrata' café-bar on the ground floor.

3.
Interior of Quadrata café.

Structure

Existing building

With very limited information available on the existing structure, a staged investigation was made to determine its construction, so as to assess its load capacity for future use. It was found to have a steel frame encased in concrete with filler joist floors (steel joists at close centres fully encased in concrete with nominal reinforcement).

The perimeter columns are built into the external solid brick walls. The basement and sub-basement are of reinforced concrete, with the sub-basement raft at least 1.8m thick.

When the building was constructed, a heating system was cast into the concrete encasement, consisting of pipes running up the columns and pipe loops in the bottom of the slabs. The intention was to provide heating without compromising the use of the floors.

A side-effect of this method of heating was that it had cracked the external brickwork at column positions, due to differential movement between the heated concrete encasement which expanded and the brickwork held at ambient temperature. This had led to limited corrosion: the cracks did not generally extend through the concrete encasement. The cracked bricks were replaced and the concrete encasement reinstated as part of the works.

The scheme required the construction of a new floor on the roof of the existing building by adding a new lightweight steel roof. This was made easier as allowance had been made for extension by stub columns in the original design.

Load test

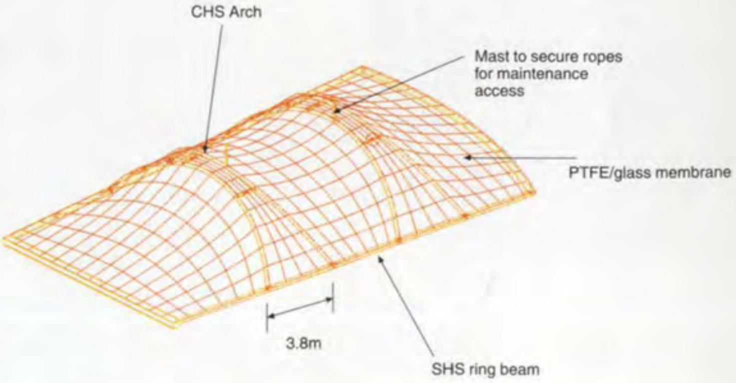
The client was keen to meet institutional standards for the floor loading. Calculations on the existing floor structure gave conservative results, as it was impossible to reflect the degree of composite action between the steel and concrete, so a load test was carried out on an area of floor slab on the first floor. The area was chosen such that full load was applied to typical beams as well as two bays of floor slab. The total load applied, in sandbags of known weight, was 90 tonnes. This equated to approximately 8.0kN/m^2, added in increments of 7.5 tonnes and removed in increments of 15 tonnes. The load was applied uniformly over both floor bays, and removed completely from one bay before the other to check the effect of continuity of the floor slab.

The maximum recorded deflection was 4mm, which returned to zero after the load was removed. There were no visible signs of distress at any location, and the recorded deflections were much less than those predicted by calculation. Permissible loading results from the tests were significantly higher than those calculated using simplified assumptions.

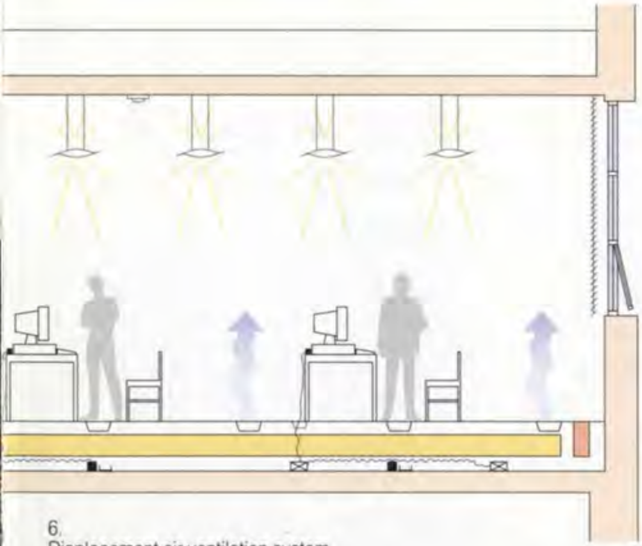
The atrium

As originally built, the building was U-shaped, with the space forming a lightwell which stopped at the ground floor; around this the upper floors stepped back up the building. A major part of the new construction was to create an atrium in this space. The roof over the ground floor was removed and the upper floors extended to give the space vertical walls, within which a new lift core with a cantilevered staircase was built. The open end of the atrium was enclosed with a glazed wall and covered with a membrane roof. A simple form was chosen, supported by two pairs of inclined CHS arches. A continuous steel RHS ring beam supports the edge of the membrane.

4 left:
Seating area
in front of Quadrata café.



5 above:
Steel and membrane roof
over the atrium.



6\.
Displacement air ventilation system.

7\.
Detail from the first floor entrance to the Arup office.

8\.
Interior of Arup office

Environmental services

The shape, orientation, and targeted tenant use all indicated mechanical ventilation and comfort cooling, as natural ventilation could not be relied on to give the kind of conditions required. An underfloor plenum ventilation system (displacement ventilation) was used, with air discharged into the raised floor plenum void from two central air plants in the sub-basement via a series of fabric ducts, ensuring a near-constant air pressure across the floor plate. The pressure was that required by the twist type displacement floor air outlets. The conditioned air is supplied at between 18-22°C, depending on seasonal variations. At this temperature range the air is close to occupant comfort conditions, the displacement system producing rising air patterns which work in conjunction with natural convection currents generated by people and office equipment.

This approach was selected as it makes best possible use of the high internal spaces (3.2m including a 600mm floor plenum) and the thermal mass of the retained existing structure. Also, it maximises free cooling by outside air, which is enhanced (between 1-2°C) by bringing in the air at low level on the north façade and using the sub-basement ventilation plantrooms as large intake plenums. Thus the thermal mass of the sub-basement pre-cools incoming air during the summer.

The building is controlled by a Building Management System which uses direct digital control technology. In addition, several monitoring devices log the building's performance.

Displacement air also discourages mixing at high level and dilution of the supply air with contaminated air already in the room. Air is extracted from the offices at high level and distributed back to the air-handling plant.

Cooling is provided by a low ozone depletion (R407C) chiller with a remote air-cooled condenser on the roof. The chiller incorporates a fully automatic refrigerant pump down facility. The top floor, surrounded by panoramic glazing and covered with its lightweight roof, needs additional cooling from low-ozone depletion (R407C) VRV multi-split type underfloor cassette units. Like the main chiller system, they have been provided with a refrigerant pump down facility.

Low pressure, low Nox, gas-fired condensing boiler plant in the sub-basement heats the building through a perimeter system, whilst the central atrium and entrance area are heated by an underfloor low pressure hot water system.

As part of the works, an additional building management terminal was installed in Arup's first floor office area, which will enable monitoring of the performance of the M&E installations and energy consumption of the building in the coming years.

Electrical services

An existing Northern Electric substation in the basement provided the starting point for the electrical installation. Whilst the predicted 700kVA maximum demand exceeds that of the original building, discussions with Northern Electric proved the existing substation capacity to be adequate for the building, together with other existing customers. Each of the seven tenant areas receives an independent Northern Electric supply, and for future flexibility the distribution arrangement allows relatively easy tenant area sub-division.

General-purpose small power supplies across the floor plates utilise a 63A rated busbar within the accessible raised floor. Connected to the busbar are twin socket outlets on 3m flexible leads, suitable for loose mounting on the slab within the void at positions to suit furniture layouts. Above each outlet, flush-mounted grommets in the floor tiles access the sockets below. Tenants are required to provide multi-socket arrangements integrated in their furniture and connected directly to the sockets in the floor void. The same grommets also provide a route for IT cabling to the desks. As well as overcoming the eternal problem of faulty floor box lids, the grommet solution proved very economical with respect to the developer's installation costs. It remains to be seen how tenants like the solution.

The dominant feature of the open plan office spaces are the existing, exposed, downstand beams, which drop about 600mm below the existing exposed slab to create large 'coffers'.

The main lighting in these areas comprises suspended continuous luminaire assemblies, co-ordinated with the beams. To accentuate the ceiling structure and provide greater visual interest, some 30% of the light output is upward. High efficiency TL5 lamps have been used, giving a lighting load of only 12W/m^2, for a design maintained illuminance of 450lux.

Amenity spaces throughout the building are lit primarily by compact fluorescent downlighters, together with 12V tungsten halogen accent lighting. Emergency lighting is provided throughout all areas using self-contained conversion units.

The building's comprehensive fire detection and alarm system is analogue addressable and is operated by the landlord as a site service.

Because the downstand beams each form a smoke reservoir, significantly more detectors have had to be provided than standard spacing criteria allow. Other standard landlord-operated security services are provided, including intruder alarm system, CCTV coverage, and controlled access to the basement car park.

The landlord has also provided a 100-seat conference room for tenants' use and also external bookings.The room is equipped with a full audio/visual presentation system.

Finally, two 800kg, 10-person bottom-drive electric traction lifts operating as a duplex pair give a good alternative to tenants not wanting to take the vertigo-inducing open atrium staircase.

9\.
Approach to the lifts on the ground floor.

The 'Vulcan' sculpture

Standing at the entrance of the refurbished building is a huge bronze figure representing Vulcan, Roman god of fire, by Sir Eduardo Paolozzi. The 7m figure may only be around one third the height of 'The Angel of the North' in Gateshead[1] but is an imposing sight as one approaches the building.

The sculpture was commissioned by Parabola Estates to reflect the local industrial heritage of the area, including the birthplace of Stephenson's 'Rocket' and shipbuilding on the River Tyne.

The sculpture was cast in three sections at a foundry in Stroud, Gloucestershire, and transported north.

The foundations were designed so that the exact orientation of the figure in relation to the space around could be decided when it was erected.

Vulcan was described in *Virgil's Aeneid* in terms that equally conjure up 19th century Tyneside: 'scooped out of the action of the Cyclops' fires; you can hear the clang of hard blows on the anvils, the roaring when masses of ore are smelted within, and a throbbing blast of flame from the furnaces.

Here is Vulcan's place.'

10.
'Vulcan for Newcastle'.

BREEAM

BREEAM was originally introduced in 1990, in an attempt to provide authoritative guidance on ways of minimising the adverse effects of buildings on the global and local environments while promoting healthy and comfortable indoor environments. In the UK it has been widely accepted as representing best practice.

It was decided in discussions with the client to undertake a BREEAM Assessment using the latest 1998 version for offices, with the aim to achieve an excellent rating. The assessment was made during the design stage with third party certification by ECD Energy and Environment. The assessment covers several environmental issues including.

- Management - overall policy and procedural issues
- Health and comfort - indoor and external issues
- Energy - operational energy and CO_2 and location issues
- Transport - transport-related CO_2 and location issues
- Water - Consumption and leakage-related issues
- Materials - environmental implications of materials selection
- Land use - Greenfield and brownfield site issues
- Site ecology - ecological value of the site issues
- Pollution - air and water pollution issues (excluding CO_2).

From the beginning we wanted to set performance targets for the M&E installations, based on the ECON Guide 19 energy efficiency in offices, 1998. Targets for thermal energy were set at 79kW/m^2/annum and for electrical energy 100kW/m^2/annum, which reflected a modern office environment. These proved a good yardstick for the design of the building as a whole, as many simple energy-saving features were incorporated into the building form and layout, reducing the need for excessive heating or cooling provision.

The building is the first refurbished office development in the north-east of England to receive an 'excellent' BREEAM rating.

Partnering

The principles of partnering have long been debated. At its best, it is a way of a team working together for the good of the whole project to build trust, mutual respect, and openness, removing barriers and ensuring that all efforts are channelled to creating and delivering the project rather than being wasted on less productive activities. This requires a team who know each other well, have worked together previously and above all, a client who wants to be involved in that process.

The team on this project gelled well. The enthusiasm created by the client, his architect, and the builder was infectious.

Meetings were held in an atmosphere where the participants felt able to contribute to all parts of the project; above all, the meetings were fun. The success of the team was illustrated by its willingness to hold a project review at the height of the construction activity. Chaired by the client, all participants (about 12 in all) were invited to list three good things and three disappointments during the design and construction process. Comments were sometimes self-critical but always constructive. This process was open and honest and displayed a willingness to learn and improve the process as a basis for subsequent phases of the development.

The client's confidence in his team and in his ability to let the building encouraged him to develop an ambitious Phase 2 project on the adjacent site, providing repeat business for all involved and the opportunity to further develop the partnering relationships.

Conclusion

The project's success is evidenced by the enthusiasm of local agents who marvel that two months before completion, all space within the building was fully let. The project has set a high standard for development in north-east England and has raised widespread interest in the urban renewal of this part of Newcastle.

In addition the project was completed on time and to the original cost budget set by the client - no mean achievement considering that it was a refurbishment. As tenants, Arup moved into the first floor during the weekend of 15-16 April, with the new office opening for business on Monday 17 April 2000. Arup looks forward to continued involvement in this urban renewal process with the Phase 2 building, now under construction.

Reference

(1) BROWN, M *et al*. The Angel of the North. *The Arup Journal, 33*(2), pp15-17, 2/1998.

Credits

Client:
Parabola Estates

Architect:
Carey Jones Architects

Building services, structural, and fire engineers:
Ove Arup & Partners Matthew Birchall, Jim Burridge, Lee Cave, David Charters, Nils Clemmetsen, Robin Comrie, Theo Devaney, Alan Dunlop, Brian Forster, Andrew Goodfellow, Stuart Graham, John Loader, Nic Merridew, Alan Rowe, Mark Stenhoff

Quantity surveyors:
Gardiner and Theobald

Contractor:
Sir Robert McAlpine Ltd

Illustrations:
1-4, 7-10: Keith Paisley
5: Nils Clemmetson
6: Penny Rees

A beacon for the City of London

Mick Brundle

Introduction

Plantation Place is a site of around 1.02ha in the heart of the City, bounded by Fenchurch Street, Mincing Lane, Rood Lane, and Eastcheap, and owned by The British Land Company plc. Arup Associates' most recent scheme there was granted planning consent in October 1998 and the site is now cleared with enabling works under way for two new buildings, comprising approximately 95 000m^2 gross of office space and retail. In Fenchurch Street midway between Rood Lane and Mincing Lane, a six-storey illuminated beacon marks the presence of the Plantation Place Marketing Suite.

1 above.
The effect of the beacon illuminated at night.

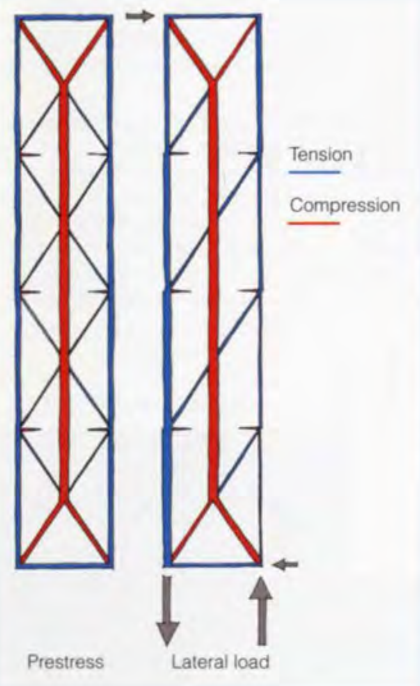
2 right:
Beacon units prior to assembly

The beacon - engineering design

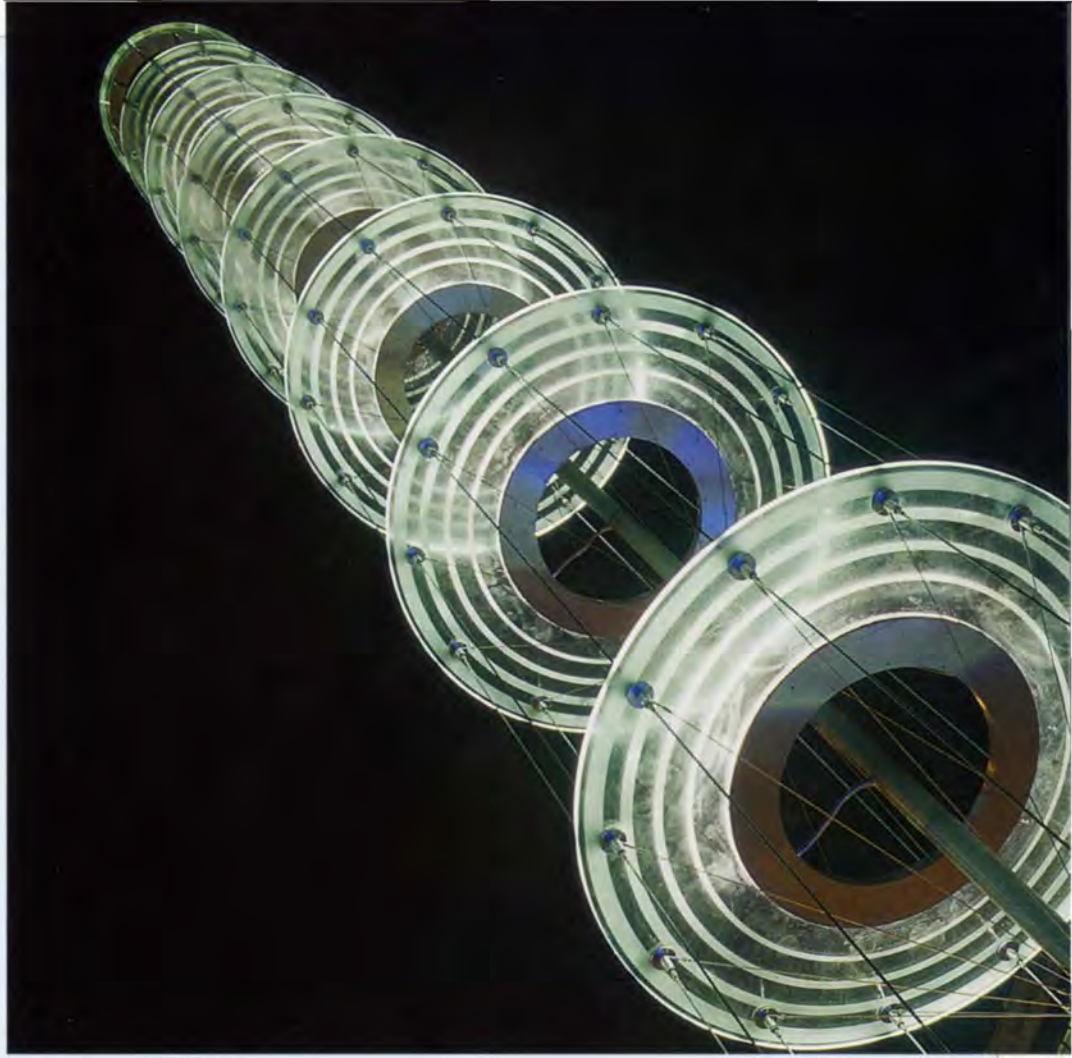
The beacon was designed as an extremely light structure that is visually transformed depending on the changing levels of surrounding light. During the day much of the structure is barely visible and at night it effectively disappears to leave only the impression of eight glowing glass discs hovering in space. This delicacy was achieved by an innovative use of the glass discs as structural elements in the tower.

The beacon structure can be described as a prestressed three-dimensional vertical truss cantilevering 27m from its base. The chord elements to this truss are 12 vertical stainless steel rods, 11mm in diameter, around the perimeter of the tower.

The 2m diameter laminated glass discs act in compression, combined with 4mm diagonal stainless steel rods to resist shear forces.



3 above:
Two-dimensional force diagram.



4.
Owing to the lighting design the glass discs appear to float in the night sky.

The whole system is prestressed by a central 114mm diameter stainless steel strut which passes through the centre of the beacon without touching the glass discs. Lateral restraint against buckling of the pole comes from sliding stainless steel collars at 3m centres to which the diagonal rods are connected. Prestressing ensures that under service wind loads, all rod elements remain in tension. The bending due to wind load on the structure is resisted by tension increasing in the chord elements on one side of the beacon and decreasing in those on the other. The compression force in the central pole remains constant.

As the beacon relies on prestress of the vertical and diagonal rods for stability, the erection sequence was critical. Working with the contractor, a method was devised by which it was assembled in eight separate modules suspended from a mobile crane, commencing with the uppermost, and working downwards. This sequence ensured that the vertical chord rods and diagonals always remained in tension under the dead weight of the modules. After the final module was attached, prestress was applied to the system by a hydraulic jack at the bottom end of the centre strut with the whole beacon still hanging from the crane.

All vertical chord and diagonal rod elements were fabricated slightly shorter than their final lengths to ensure that after jacking the centre strut, all elements received the correct level of prestress.

The structural design is complemented by the lighting design, which enhances the impression of the glass discs floating in the night sky. Each low-iron glass ring has a mica top surface formed by small clear glass pieces fused into the surface, and the underside sand-blasted with concentric rings.

Each glass ring is lit from its inner edge by a circular luminaire box containing 16 compact 18W fluorescent lamps arranged radially. The light travels through the glass and is partially emitted through the sand-blasted powder surface with the remainder emerging from the edge. The uppermost ring has a smaller inner diameter and is lit by a four-quarter circle cold cathode. The beacon is surrounded by floor-mounted light-emitting diode marker lights which provide a blue wash to the lowest of the glass rings.

Credits

Client:
The British Land Company PLC

Architects & engineers:
Arup Associates Mick Brundle, Tristram Carfrae, Pat Clowry, Damian Eley, David Hymas, Mike King, Jonathan Rose, Haico Schepers, Matthew Vaudin

Quantity surveyor:
Gardiner & Theobald

Main contractor:
Kvaerner Trollope & Colls

Key subcontractor:
Haran Glass

Illustrations:
1,4: Grant Smith
2: Matthew Vaudin
3: Mick Brundle

Forum Roof, Sony Center, Berlin: Innovation beyond 'form follows force'

Ross Clarke Bruce Danziger Markus R Schulte


1.


2.


3.

Above:
1. Potsdamer Platz before World War II.
2. 'Straße unter den Linden', 1939.
3. Berlin in 1945.

Introduction

As a result of World War II and the political situation in Europe, Berlin was physically divided into West and East Berlin - very different in their political and economic systems. Potsdamer Platz, the old centre of the city, was destroyed and, due to its proximity to the Berlin Wall, was never rebuilt (Figs 1-3).

After German re-unification in 1989, the city and the federal government initiated several international architectural competitions for renovating significant buildings and rebuilding important urban spaces in Berlin. In 1992 the German-American architect Helmut Jahn, assisted by Arup's New York office, won the competition for Sony's European Headquarters on the western edge of Potsdamer Platz.

The whole complex consists of seven buildings with a gross floor area of 212 000m^2. Their average height is around 40m, though one office building exceeds 100m. The use of the buildings varies: offices and apartments in the upper floors, retail and restaurants at ground floor levels, movie theatres in the basement. The *Deutsche Mediathek* with a permanent 'Marlene Dietrich Museum' and the *Filmhaus* will be in one building. The only one remaining after World War II is the former Grand Hotel Esplanade, which was integrated into the new complex. Excavation for the project started in November 1995, with completion scheduled for June 2000.

Arup's role on the project includes structural engineering for four of the buildings, and the structural and environmental engineering for the Forum. This elliptical plaza, the focus of the entire project, is crowned by a spectacular and innovative roof.

Design

The design and the concept for the roof evolved during the competition in 1992 in a collaboration between Helmut Jahn and Arup's New York-based engineers. The initial concept remained essentially unchanged from the 1992 competition to the completed project in spring 2000.

The roof is the centrepiece of the project, and is designed to extend the use of the Forum plaza during inclement weather. The space created under the roof was not supposed to be air-conditioned, and the city's building department had demanded special requirements for ventilation and daylighting. Due to the project's proximity to the Reichstag, Jahn did not like the idea of a dome-shaped roof covering the elliptical space. It was important to him that a roof should cover the plaza like an umbrella. It was not meant to be sealed, nor should it disconnect users from an outdoor experience (for example listening to a concert on a warm summer night).

Prior to the detailed design of the roof, Arup conducted an environmental study which used wind tunnel tests, dynamic thermal modelling, and computational fluid dynamics analysis to assess comfort levels within the Forum space. The study quantified the extent to which the Forum space would be usable throughout the year for special events as compared to an un-covered space. The improvement was found to be significant and helped to support the roof concept.

In general, roof structures require evenly distributed openings of only 15% of the their surface area to provide sufficient daylighting to the space below. Completely glazed roof structures with an average light transmittance of up to 85% can result in undesirable heat gains. This factor contributed to the decision to use teflon-coated fibreglass with a translucency of ~17.5% as an additional material for part of the surface of the glazed roof.

A hyperbolic cone was arrived at to describe the surface of the roof. Sections through a cone perpendicular to the axis of symmetry are circular in plan, while sections through it at an angle are elliptical in plan (Fig 4). The elliptical Forum of the Sony Center implies an elliptical section through a tilted hyperbolic cone, which in turn creates the roof surface. The circular opening in the centre of the roof, reflecting a perpendicular section through the hyperbolic cone, marks a circular pool on the floor of the Forum. This mathematical concept provides an axi-symmetric surface and the geometrical discipline needed for the structural integrity and buildability of the roof.

The structural system

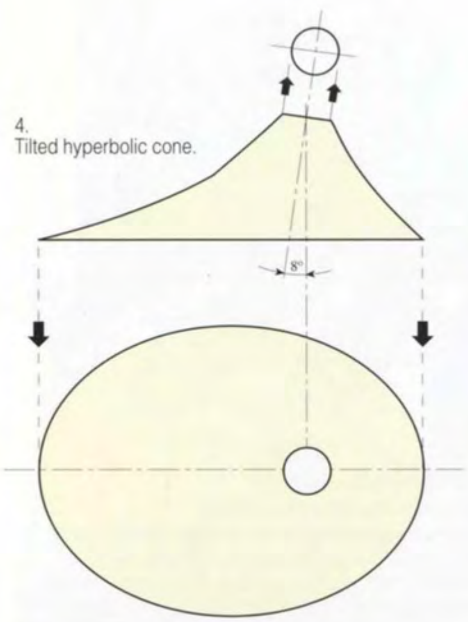
The structure for the roof is therefore based on the geometry of a tilted and cut hyperbolic cone and picks up the principles of a bicycle wheel. A continuous ring beam was placed along the edge of a tilted cut through the hyperbolic cone, resembling the rim in a bicycle wheel. The two top chords of the triangulated ring beam follow the surface of the hyperbolic cone. The ring beam is elliptical in plan with spans of 102m (335ft) in the main axis and 78m (256ft) in the minor axis (Fig 5).

A 42.5m (139ft) long kingpost was arranged in the tilted axis of symmetry of the hyperbolic cone, resembling the axle in the bicycle wheel. Two radial layers of cables connect the top and the bottom of the kingpost with the ringbeam (Fig 6). The top layer - the ridge and the valley cables - creates the folded surface of the roof. The bottom layer of cables, the kingpost cables, suspends the kingpost over the Forum.

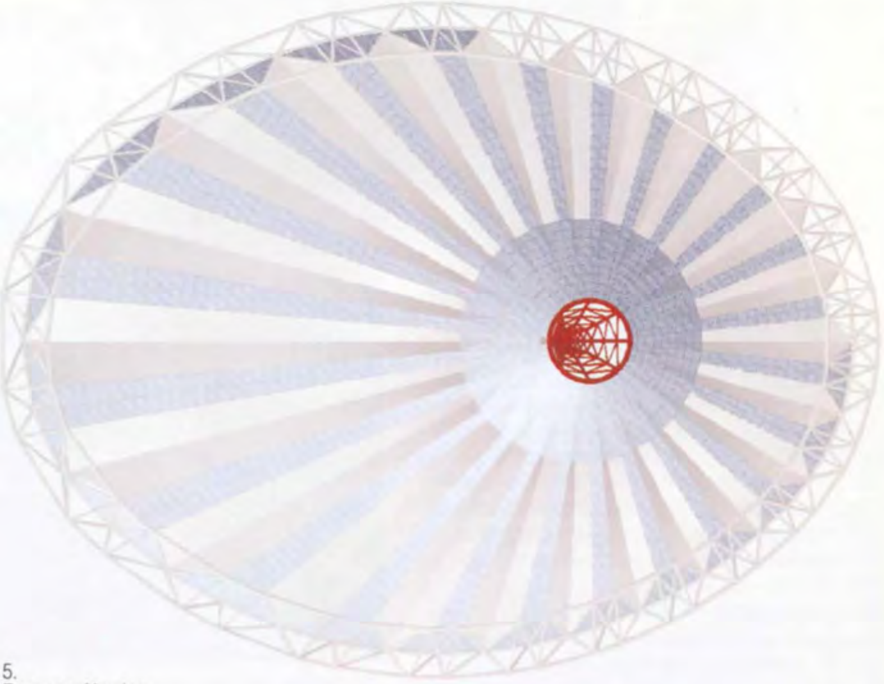
The whole system is prestressed to stabilise the surface created out of cables, fabric, and glass. The ringbeam is supported vertically at seven points on the top of the roofs of the buildings surrounding the Forum. Horizontally, the support configuration is structurally determined to avoid locking any forces from the roof into the buildings or - vice versa - from the buildings into the roof.

(a)
Site-welded segment of the ringbeam ready for lifting.

(b)
Completed ringbeam on top of buildings.



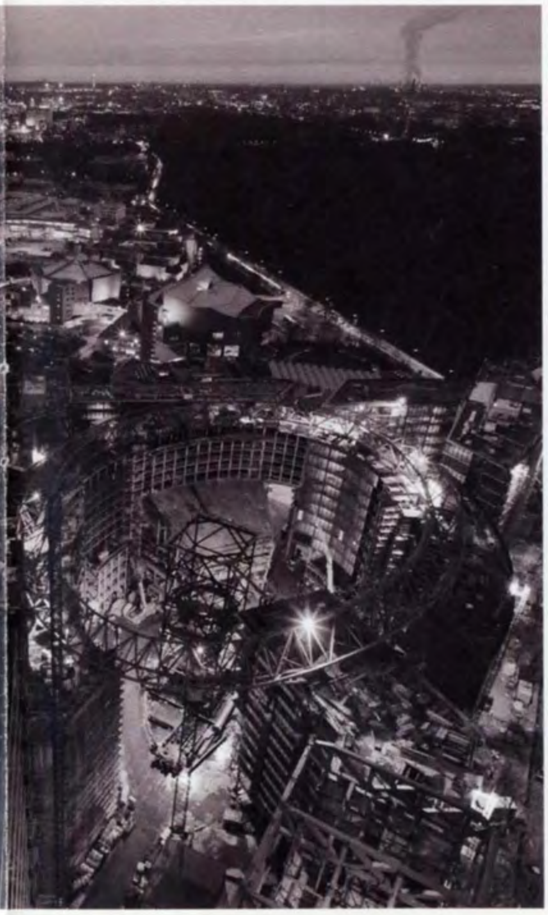
4.
Tilted hyperbolic cone.



5.
Forum roof in plan.

6.
Forum roof in elevation.

(a) to (k)
Construction sequence of Forum Roof.



(c)
Prefabricated kingpost supported in scaffolding.

Design process

Overview

Following the competition, Arup was appointed in 1995 to provide engineering services for all design stages of the roof.

This included preparing construction documents, negotiating with the building department and their respective representatives, assisting the client during the tender and bidding stage, supervising the materials testing, site supervision, and assisting the contractor during erection. The complete continuity in engineering services for the project proved to be a key element in the process of building this roof.

Generally accepted codes for the design of fabric structures do not exist in Germany and building permissions are only granted on a case-by-case basis. Rigorous checking of calculations and documents by the various representatives of the building department are the common procedure. In this case, additional testing was conducted to verify the assumptions in the calculations.

In the end, five separate special permissions were granted by the building department, allowing the project to be realised.

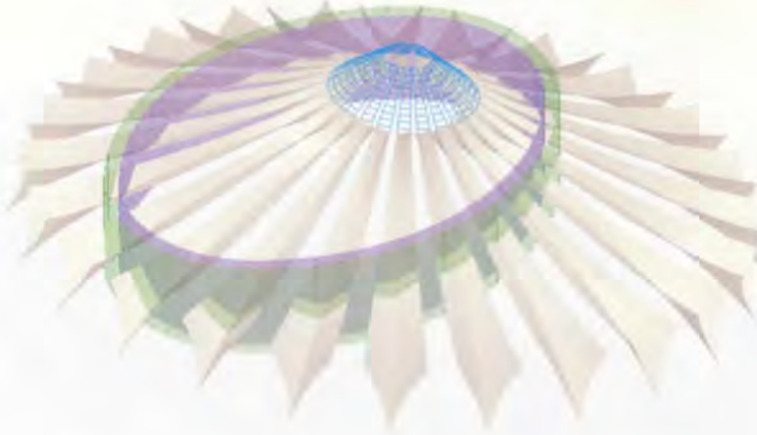
Form-finding and geometry

The stressed geometry of the Forum roof resulted from a form-finding procedure that had multiple steps. Initially, the shape of one fabric valley was form-found assuming a minimal or 'soap film' surface spanning between cables with counter curvature, two upward curved ridge cables and one downward curved valley cable 'folding' the soap film. The system finds its equilibrium and its geometry in space dependent on the chosen boundary conditions and on the prestress within the elements.

In this first step of the form-finding procedure, a uniform prestress of 4kN/m was chosen in the warp and weft directions of the 'soap film'. The ridge and valley cables were assumed to be 'soap film strings' with no stiffness and a constant prestress of 450kN. The level of prestress in the system depends on the chosen material for the fabric, external loading on the system, and the behaviour of the structure itself. The assumed value for the prestress in the fabric is on the lower allowable boundary for the chosen material (in this case *ChemFab* PTFE, *Sheerfill* V). External loading on the system usually results in an increase in fabric forces.

In the second step of form-finding, the cables were assumed to have stiffness, and the fabric was again modelled assuming a 'soap film' surface. The aim of this step was to compensate for the distortion in the geometry of the fabric due to the influence of self-weight. The self-weight of the structure and the glass was applied along the cables. In this step of form-finding, the force within the fabric remains constant at 4kN/m. The geometry of the cables changes and the force within the cables varies from 425kN to 475kN.

The next step in the procedure assumed stiffness and self-weight in all structural elements, including the fabric. First, structural calculations were undertaken on this model, with the aim of investigating the possibility of ponding under maximum vertical loading. The chosen requirement was that under 90% prestress and 150% snow loading no ponding will occur, and that there still should be tension in the valley cable. Several models were investigated before this criterion could be satisfied.


7.
Tilted hyperbolic cone with 'cookie cutter'.

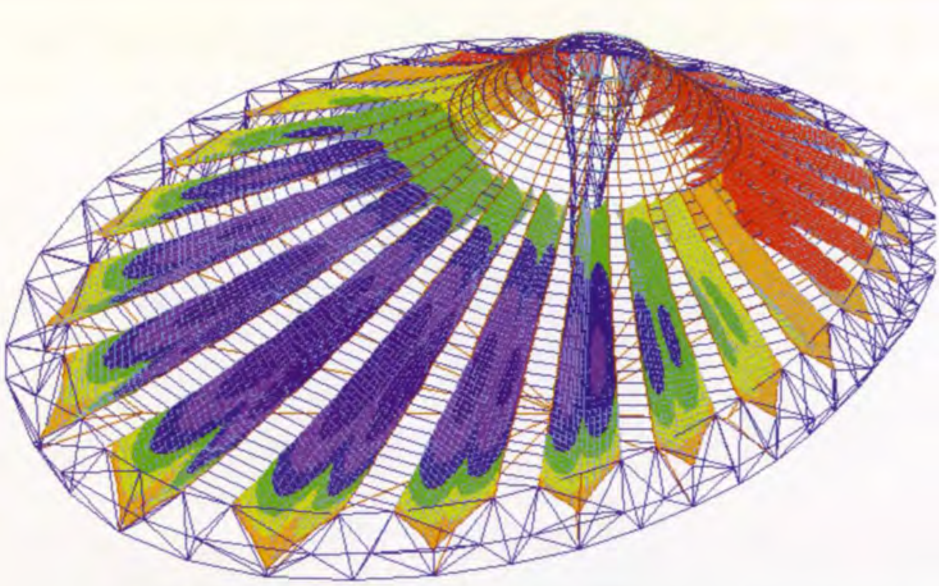
The finally chosen fabric valley describes an angle of 10° in plan; it consists of one fabric valley, folded by two ridge cables and one valley cable. This unit was rotated in angles of 15° around a central axis, creating the previously described hyperbolic cone (Fig 7). Ring elements with a constant spacing of 1.5m close the 5° gaps between the fabric valleys, closing the ring forces within the system and serving as supports for the glass. This hyperbolic cone was now tilted by 8° and, with an elliptical 'cookie cutter', the surface of the roof was cut out of the hyperbolic cone.

The ellipse of the 'cookie cutter' resembles the plan of the Forum below the roof. A circumferential ringbeam was orientated along the chopped edge of the hyperbolic cone, with the kingpost in the tilted axis. Both elements pick up the tension forces within the cables and create a closed structural system resembling the bicycle wheel.

(d)
Fabric segments being craned into position.

(e)
Fabric segment being connected to ridge and valley cables.

Sequence continues: ▶



8 left:
Maximum vertical deflection of the roof under maximum snow loading is ~1m (40in) = L/60 (!).

The deformations of the ringbeam distort the level of prestress in the fabric and in the cables, which would have distorted the hyperbolic cone. In a final step of form-finding on the whole system, the deformations of the ringbeam were determined and compensated. This required the unstressed geometry of the ringbeam to be built slightly bigger than its final stressed configuration.

Calculations and material testing

Calculations and various methods of testing on mock-ups were used to prove the integrity of the structural system and the serviceability of the glass and its connections to the structure. All these calculations and tests were co-ordinated early in the process with representatives of the building department, and were conducted with three different computer programs: Fablon, GSA and Sap2000Plus. All these consider geometrical nonlinearities and at least partially allow consideration of material-dependent nonlinearities.

The basic prestressed configuration of the roof under dead load was used to check the results of the programs against each other.

A complete model of the roof with ~55 000 nodes was used to investigate the strength of the elements and serviceability of the glass. The design of the elements is based on the European Code's 'Load and resistance factor design' assuming different safety factors for each load case. Approximately 45 different load cases with different safety factors were investigated. It took about one full day to calculate each load case, and the results were post-processed graphically and in spreadsheets.

As well as the regular safety factor for permanent loading (here 1.35), a factor of 1.10 or 0.90 was applied to the prestress to compensate for tolerances during construction and to allow for a loss in prestress in the fabric over time.

The values for the stiffness of the fabric - which can vary considerably depending on the material - were determined in biaxial testing.

The results of the calculations show that snow loading governs the design for strength and for serviceability. Under full snow loading (Fig 8) the maximum vertical deflection of the main fabric valley spanning from the kingpost to the ringbeam is ~1.0m (~40in). Related to the span of the longest valley it resulted in a deflection / span ratio under live loading of L/60. That amount of deflection is beyond any code regulation.

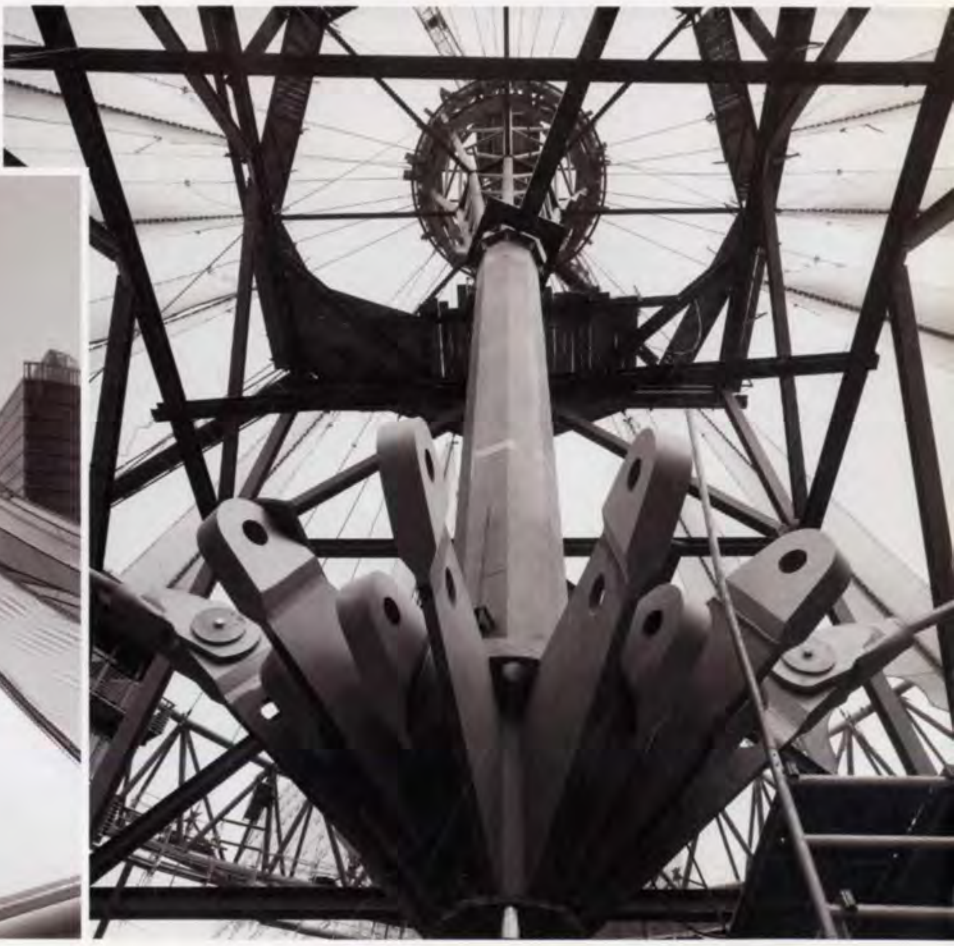
The most critical issue for the design of this roof is the serviceability of the glass panels. The position of a rectangular pane of glass is defined in space by three points; if a rectangular glass panel is supported in more than three points, the movements of these points relative to each other under loading must be established. The maximum calculated warping under snow loading of the fourth corner out of the plane of a glass panel was found to be 25mm. The maximum rotation of a glass panel was calculated to be 0.9°, resulting in 22mm movement to be taken by the connections of the glass to the structure.

Testing verified that the glass panels could undergo such amounts of warping and that the connections and joints could handle the movements. All glass panels had a constant width of 1.5m (5ft) and were up to 5.4m (18ft) long. Each rectangular glass panel consisted of two heat-strengthened panes of

▶ ***Construction sequence continued:***

(f)
Rectangular hollow sections connecting the fabric valleys.

(g)
Bottom kingpost cables installed after fabric installation.




9.
80mm warping of the panel / 80mm translation at the connection without failure.


11 above:
Broken laminated glass panel with 75kg/m² (16psf) loading.

glass, each 8mm (0.3in) thick, laminated together with 1.52mm (0.06in) thick PVB interlayer. Testing showed that a 1.5m (5ft) wide and ~3m (10ft) long glass panel could be warped out of its plane 80mm (~3.15in) without failure. Also, the connection of the glass to the structure, an elastomeric buffer, could be shifted 80mm (~3.15in) without failure (Fig 9). Additional testing investigated the strength of a broken glass panel to ensure the integrity of the structure under certain specified conditions (Figs 10, 11).

Design of fabric

The fabric was designed according to the German concept that assumes 'reduction factors in strength' for the material used, based on allowable stress design. The ultimate tensile strength of the material is divided by the product of all reduction and safety factors, providing an allowable maximum force in the material under service loading. In testing, the following reduction factors were determined for the warp direction of the fabric used:

A1 = 2.10 reduction factor due to long-term loading (considered for a 50-year period)

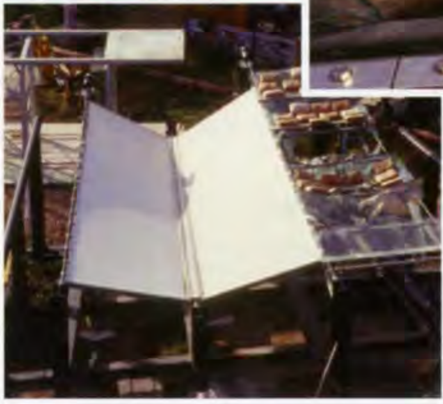
A2 = 1.10 reduction factor in strength due to environmental influences (UV light, etc)

A3 = 1.00 reduction factor due to the influence of temperature

A4 = 1.23 reduction factor due to the influence of the connections

S = 2.00 global safety factor for strength.

The overall global safety factor for designing the fabric under service loading in the warp direction in this case was A1 x A 2 x A3 x A4 x S = 5.68. That led to a maximum allowable force of 19.8kN/m in the warp direction.


10.
Mock-up with broken glass panels.

Tearing due to punctures during erection was another important factor to consider for the integrity of the structure and for the serviceability of the glass. In a first worst case scenario it was assumed that a whole fabric valley would tear over its entire length. Calculations proved that the structure would still be stable, but glass panels would be likely to fail near the torn fabric valley. Additional testing showed that small punctures in the fabric would reduce its strength substantially. A 30mm wide tear started to propagate at only half the ultimate strength of the material. A wider initial tear would start to propagate at an even lower force. However, testing showed that the length of a tear within one fabric valley would be limited and would not tear a whole fabric valley over its entire length.

Design of connections and construction documents

From the beginning of the design, the engineers and the architect developed connection details for the structure, the fabric, and the glass. During bidding, these details and all other documents were made available to contractors for comments and input. Arup made calculations to prove the integrity of the details at this stage to avoid any 'surprises' later. When the contract was signed for erecting the roof almost all details were fully determined in appearance and size, and later built according to Arup's initial specifications.

One of the most important details is the connection of the glass panels to the structure. Arup's initial design assumed stainless steel bearings with sliding joints and ceramic washers. However, this detail was later simplified and improved significantly in consultation with the contractors during bidding. The final design comprises an elastomeric buffer to allow the glass surface to 'float above' the structure, capable of undergoing large movements.

Geometric control was especially important for erecting the roof. The most critical geometric information was developed and defined by Arup: the two 3D centreline models of the roof, showing the exact stressed and unstressed geometry of the structure in x, y, and z co-ordinate points.

(h)
Kingpost cable connection at the bottom of the kingpost.

(i)
Prestressing the roof by telescoping the kingpost (Jack force 15 000kN).

As already noted, this roof erection can be described as the connection of 'too short' (fabric and cables) and 'too long' elements ('ringbeam'). Only when all have been connected will the 'perfect' geometry of the form-finding procedure appear. This concept allows a 'history-independent' erection sequence and gives contractors freedom to use individually preferred procedures.

Building tolerances were compensated in the end connections of the cables; cylindrical sockets with external thread allowed for adjustment to cable lengths. The geometry measurements during erection showed that single node points of the ringbeam were off the theoretical system points by up to ±90mm (±3.5in). That was in the order of the absolute strain elongation of the cables and would have resulted in a huge error in the level of the predicted cable forces.

Tender and award

The Forum roof was part of the contract for the whole Sony Center. Hochtief was appointed as general contractor in autumn 1996, and they subcontracted the roof to Waagner Biro in winter 1997. During tender, Arup worked closely with the client and in due course with the selected main contractor, producing a technical manual specifying materials, procedures, surface treatment, material testing, etc, as well as detailed calculations and drawings

The following quantities were part of the tender:

Ringbeam:
500 tonnes steel S355J2H,
circular hollow sections

Kingpost:
90 tonnes steel S355J2H,
circular hollow sections

Cables:
120 tonnes fully locked cables

Castings:
50 tonnes steel, GS - 18NiMoCr36
according to SEW 520

Fabric:
5250m^2 (56 500ft^2)
Teflon-coated fibreglass

Glass:
3500m^2 (38 000ft^2)
heat-strengthened laminated glass,
2 x 8mm (0.3in), low iron, ~ 0% translucency

Due to the use of different materials, the roof contractor had to find additional subcontractors to build it. Several technical meetings were held to give contractors the chance to ask questions and give them detailed information on the design concepts. The most important issue for the client representative was to find individuals in a potential contractor who were technically capable, showed innovative potential, and understood that it needed a team effort to realise such a difficult project ('no complainers, no know betters').

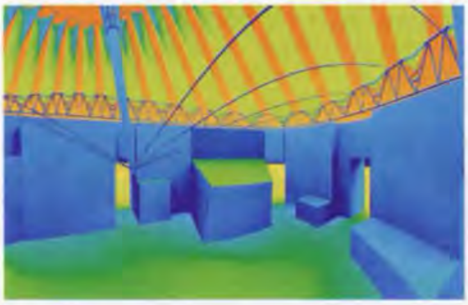
In the end Waagner Biro was appointed to built the roof for ~DM20M or DM3333/m^2 (US\$10M, US\$155/ft^2). They proved truly able to take on the challenges of building the roof.

Daylight study

As part of the approval process to obtain building permission, the building department demanded a rigorous technical proof that the strict German daylight requirements, as defined in various national codes, were fulfilled in the many offices and apartments facing the plaza under the roof.

In that context Arup conducted a 'daylight study' using computer simulations to assess the daylight levels (Fig 12). It was completed and submitted in May 1998 and the results were discussed with the representatives of the building department, mainly German University professors. The study was approved in July 1998 and, in conjunction with the material testing, a building permission was issued to the owner.

12.
Daylight simulation of the space below the roof.



The challenge was to precisely model the complex passage of natural light through the roof and by inter-reflection into the offices and apartments. Daylight levels in individual rooms had to be predicted and compared with the code requirements. The challenge was met by the application of innovative ray-tracing computer techniques to support established daylighting design experience. A methodology was developed that determined light levels in a few key rooms, from which conclusions could be drawn on the conditions in all other rooms in each building. A highly detailed 3D-computer simulation model was built including not only the complex geometry of the roof, but also physically accurate modeling of the transmission and reflection of light from the roof and building façades.

Conclusion

The Forum roof is unique in its design, its urban context within Berlin, its scale, and the structural use of different materials. The project became an expression of a group of people who grew together during the process of designing and building it.

Reference

(1) HORN, R. Structure and light: the roof of the Sony Center at Potsdamer Platz. Berlin, Nicolai, 2000.

Credits

Client:
Sony

Project developer:
Tishman Speyer Properties, New York & Berlin

Architect:
Murphy/Jahn Architects

Structural, lighting, and environmental engineers:
Arup Ross Clarke, Bruce Danziger, Ken Goldup, Greg Hodkinson, Jayant Kumar, Mahadev Raman, Markus Schulte, Nigel Tonks, Steve Walker

Design review & checking authority for building department:
Prof. Joachim Lindner, Berlin

General contractor:
Hochtief AG

Roof contractor:
Waagner Biro AG

Fabric subcontractor:
Birdair, Buffalo NY

Illustrations:
1-12: Arup
(a) to (k): © Roland Horn, Berlin

(j)
Prestressed roof with free floating valley ring.

(k)
Installation of the glazing.

Alfred Lerner Hall, Columbia University, New York

Bruce Danziger
Matt King Ashok Raiji

2.
External view of the glass wall spanning between the original campus buildings.

Introduction

The Alfred Lerner Hall is a new 270 000ft^2 (25 000m^2) student centre on the main campus of Columbia University, in upper Manhattan, New York. The building serves as the focal centre of student activities, providing a 1600-seat auditorium, a cinema, conference facilities, campus radio and TV stations, offices, student clubs, and offices for community organisations.

The original masterplan for the campus was developed at the turn of the century by the New York architectural practice McKim, Meade, and White, responsible for many of the city's best-known historic landmarks. Their concept was to lay out a series of open courtyard, masonry buildings, creating a rhythm of solids and voids around a large lawn. The new student centre is prominently located on the south-west corner of the lawn, and links the campus with Broadway on the west side of the site.

The University commissioned two architectural practices to lead the design - a collaboration between Gruzen Samton and Bernard Tschumi Associates. They responded to the framework of the masterplan by adding to the main building two brick-clad wings, housing the functional parts of the scheme.

The central courtyard void was then enclosed with a glass wall to create a circulation hub (Figs 1 & 2).

As they had worked together on many projects, Tschumi called in Hugh Dutton of RFR as a design consultant on the glass wall, and after Dutton left RFR he continued on in this role throughout the rest of the project. Arup's role was to design the mechanical, electrical, and plumbing systems, together with the IT and communications. Arup also designed the glass wall structure, while New York consultants, Severud Associates, completed the structural design of the base building.

Building concept

The internal layout is driven by the need to link the campus to Broadway, which involves a 6ft (1.8m) drop in elevation. To resolve this change in level, the floors on the Broadway side were set a half level lower than those in the campus wing, with the two sides connected by a spiral of ramps in the hub.

Three ramps are arranged on the north glazed façade, rising from west to east, while concrete ramps on the south side of the hub carry people up in the opposite direction. On the east side of the hub two staircases provide shortcuts to the ramps, and at the west end, at high level, a 'skylounge' links the south ramps with the north (Figs 3 & 4).

Glass wall

Architectural concept

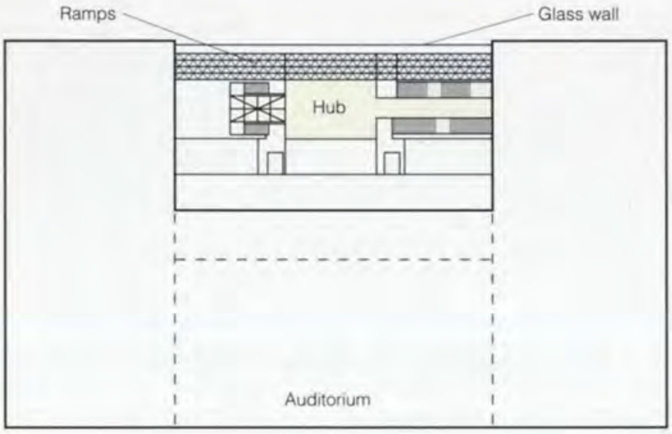
The glass wall is the centrepiece of the scheme and fulfils several roles architecturally. The glass plane itself was intended to be as transparent as possible to maintain the void concept of the original masterplan, and so it was decided early in the design process to adopt a corner bolt through fixing for the skin, to minimise the material in the glass plane. The design also called for a column-free base to the wall to leave the ground level as visually open as possible.

The architectural treatment of the space is intended to emphasise and add to the sense of movement and circulation around the hub. The glazing grid follows the slope of the ramps on the north wall, while on the south side the grid is reversed to follow the internal ramps.

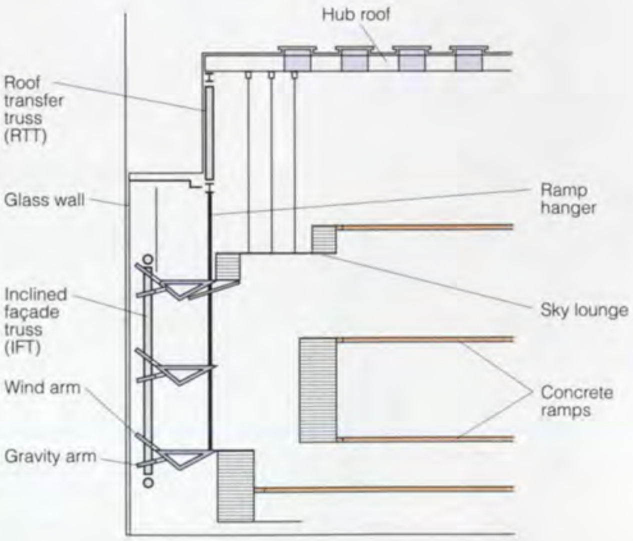
The form of the glass wall ramps was developed as a series of intersecting triangular steel planes that fly from one end of the space to the other, projecting a pattern of shadows on their translucent glass walking surfaces, lit during the day from skylights in the circulation hub roof.

The architect wanted the glass wall structure to be clearly legible. Exposed structural steel was adopted throughout, with details expressing the function and fabrication of each constituent element. The structure is subdivided into a clear hierarchy of support, with pin connections both to aid construction and to force the structure to carry load by simple, predictable load paths.

1.
Plan showing circulation hub.



3.
Section through circulation hub.



Structural concept

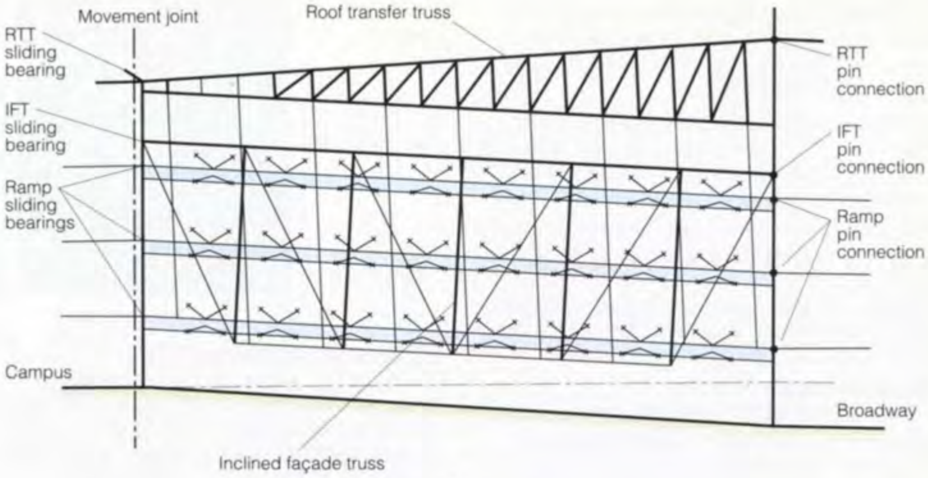
The vertical loads on the structure are supported by two primary trusses spanning 100ft (30.5m) between the base building structure, providing the column-free zone at ground level.

The inclined façade truss (IFT) is set close to the glazing plane and vertically supports one side of the ramps. Their other side is hung off the high level roof transfer truss (RTT), which also supports the circulation hub roof (Fig 5).

The vertical glazing plane is suspended 3ft (0.9m) out from the primary structure, creating a separation that emphasises the translucency of the glass. The glazing is vertically supported on gravity support arms hung off the underside of the ramps.

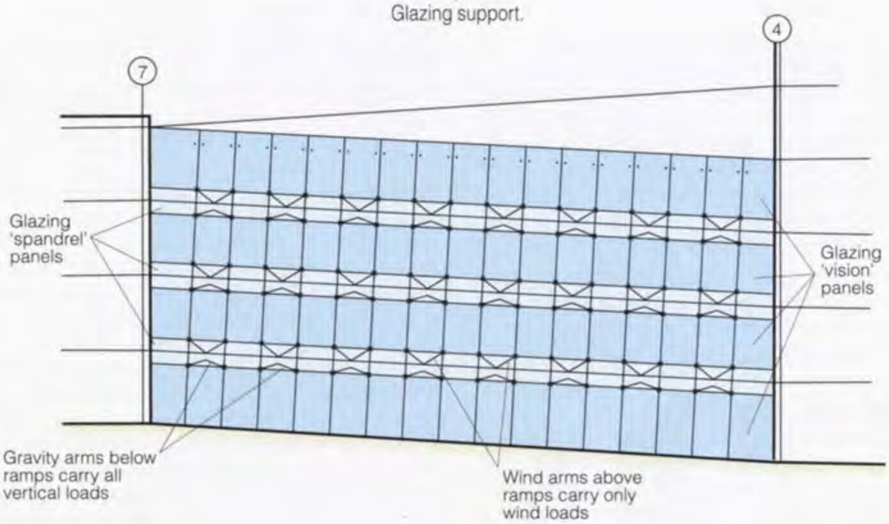
Wind loads on the vertical glazing are transferred back to the base building frame by five horizontal bracing planes. The lower three of these are formed by the ramps, which act as horizontal beams. Above them the skylight roof is braced to form a wind truss and the hub roof acts as a stiff diaphragm at the top. Seismic loads perpendicular to the glazing plane are carried in a similar manner, although in this direction they are not critical, as wind load dominates. Seismic loads parallel to the glazing plane are transferred back to the base building by the ramps and primary trusses.

A movement joint was introduced at the eastern interface with the base building structure at grid line 7. This isolates the wall from differential movements between the two wings of the base building, and allows expansion and contraction of the glass wall under thermal loads. Sliding bearings were incorporated into all the primary connections to the base building structure at grid line 7.



5.
Glass wall structure.

6.
Glazing support.



4.
Internal view
of glass wall ramps and stairs.

Glazing concept

It was decided early in the design process that each glazing panel should be individually supported, rather than the glazing being hung in series. This greatly simplified the erection process for the panels, as each could be individually adjusted. The glazing is subdivided into 4ft (1.2m) tall 'spandrel' panels running along the ramps, and 'vision' panels between the ramps, typically 8ft (2.4m) tall. The top row of vision panels is 10ft (3m) tall, and above this the glazing grid is reversed to follow the grid of the internal concrete ramps.

Panels are vertically fixed at each of the three ramps, and the top row of glazing is carried on the skylight roof structure. At the ramps, both spandrel and vision panels are vertically fixed to gravity arms, hung off the underside of each ramp. Wind arms, rigidly fixed to the upper surface of the ramps, support the other end of each panel (Fig 6).

A key concept was that the glass should not attract in-plane forces from wind loading, or live loading on the ramps. The corner fixings for each panel to the wind arms are completely isolated from in-plane loads, transferring only wind loading perpendicular to the glazing plane. The freedom from restraint provided allows the primary structure to deflect without trapping forces in the glass.

The glazing fixing, originally developed by RFR, employs a ball joint located in the glass plane, preventing the transfer of any bending moments into the glass plane (Fig 7).

At the wind arms a second rotational bearing is introduced at the glazing spider, creating a double-pinned strut between the glass and the primary structure, to provide the required isolation (Fig 8).

The primary vertical glazing is laminated to provide a robust panel build-up that will hold in place in the event of panel failure. A build-up of tempered and heat-strengthened panes was originally specified, but the contractor finally revised this to a 0.5in + 0.4in (12mm + 10mm) fully tempered panel.

Ramp structure

The form of the ramps was significantly influenced by aesthetic considerations, with the structure conceived as a series of intersecting, triangulated plates. The diamond layout of the plates on plan acts as a natural bracing system, with edge and bottom chords tying the plates together to form a three-dimensional truss, capable of spanning 100ft (30.5m) horizontally.

The ramps are vertically supported at closer intervals, providing a redundancy in the system should an individual tie fail. This also gives them a relatively high natural frequency (around 10Hz), which leaves them less prone to dynamic excitation by pedestrians. The RTT and IFT, which support the ramps, have a lower natural frequency but the overall weight they support limits dynamic accelerations to acceptable levels.

The ramp floor glazing is made up of two panes of 0.315in (8mm) tempered glass, with a translucent interlayer. Slip resistance is provided by a ceramic surface dusting of glass beads, baked on during the tempering process.

Roof transfer truss (RTT)

The RTT spans 100ft (30.5m) between the base building structure, with its shape generated by the geometry of the skylight and hub rooflines. The truss must be very stiff vertically to reduce the movements generated in the glazing plane by live loading on the ramps. 14 x 235mm jumbo I sections were adopted as chords to limit the midspan deflection under live loading to 0.5in (12.7mm) (span/2400).

The shape of the truss suggests that it could act as a propped cantilever, fixed at its western end. This action, however, would generate significant diaphragm forces in the base building slabs, adding complexity and cost to the structure overall.

To prevent transfer of these forces, a sliding bearing was introduced at the connection of the bottom chord to the base building frame at grid line 4. The top chord is connected with a 5.5in (140mm) steel pin connection, while the truss connection at the eastern end sits on a sliding bearing.

7.
Detail of
the gravity star.

8.
Detail of
the wind star showing
double-pinned struts.

Inclined façade truss (IFT)

The IFT is set between the ramps and the glass plane, so it was desirable to minimise the visual bulk of its components. As with the RTT, a high degree of stiffness was sought to limit the effects of ramp live loading on the vertical glazing.

This led to the development of a deep truss with a span / depth ratio of around 3.5, limiting deflection at the centre of the truss under ramp live load to 0.5in (12.7mm) (span/2400). The truss form is divided into tension components (bottom chord and truss diagonals) and compression components (top chord and truss diagonals). Tension elements are solid steel rods of 2in (51mm) and 3in (76mm) diameter, and compression elements are 7.625in (194mm) pipe sections.

The size of the compression elements in such a deep truss is dictated by their buckling behaviour. The truss has negligible stiffness out of plane and so is restrained by the three ramps perpendicular to the glazing plane. These connections, however, create a problem - because the top and bottom ramps are tied in to the chords of the IFT, they attract high axial forces from the overall truss action of the structure. A sliding bearing was incorporated into the pin connection between the ramp and the IFT verticals to allow free movement along the axis of the ramps, to release the forces. The truss verticals are fully tied in at their midpoint to Ramp 2 to restrain buckling - possible because the ramp lies along the neutral axis of the IFT.

Contractual organisation

Due to the complexity of the geometry and structural system, it was decided to let out the glass wall and ramps as a single package. Close co-ordination of the fabrication and erection of the system was vital to the successful completion of the scheme.The package was bid on by three groups and eventually a consortium featuring Eiffel Construction Metallique of France won the contract. This was Eiffel's second major project in New York (the Statue of Liberty was their first!). Eiffel fabricated all the steelwork in France, shipping it over to New York for erection by Precision Specialists, a New Jersey-based erector. The glass was made in Italy by Sun Glass.

Mechanical systems

Lerner Hall can be thought of as three separate buildings (campus building, Broadway building, and auditorium building), with the hub and ramps as the unifying element. The low floor-to-floor heights (12ft [3.66m] in some cases) required a vertical duct distribution system to maximise clearances in finished spaces, so fan rooms were located in each building component to condition spaces within it.

In the campus and Broadway buildings, the functional spaces are architecturally organised as perimeter areas with an interior corridor adjacent to the services core. Building services are placed in the ceilings of these corridors with a minimum amount of services distribution in the functional spaces themselves. This strategy allowed all areas of the building to have the highest possible ceilings within the limitations of the low floor-to-floor heights. The diversity of spaces in the building suggested the use of multiple air handling units to provide operating flexibility and efficiency. The primary heating and cooling media (steam and chilled water) are generated in a remote central utility plant and distributed throughout the University campus.

The hub area is conditioned using long-throw nozzle jet diffusers located outside the space. The single-glazed glass wall faces north, resulting in the lowest possible solar heat gain. Analysis showed that the ramps would be within the extended comfort envelope, given their transitory nature.

The single-glazed façade did pose a problem during the heating season - the design outdoor heating temperature for New York is 11°F (-12°C). To offset the considerable downdraft, a forced air perimeter heating system was installed at the base of the glass wall.

Lighting design

As with most large public spaces, the ambience of the hub is strongly influenced by the lighting systems. The design brief from the architects was to have the hub glow at night (Fig 10), and when viewed from the outside, people walking on the glass ramps should be in silhouette. This effect was achieved by the combined effect of low lighting levels on the glass ramps and high lighting levels at the rear wall of the hub. A lighting study using the Radiance program was undertaken to evaluate the natural and artificial lighting in the hub.

The glass façade and rooftop skylights provide adequate natural lighting during the day, while wall washers and high level floodlights give background lighting at night. Cold cathode tubes run along the underside of the glass wall ramps, highlighting their surface with a cool blue at night.

The use of Radiance modelling was very successful both as an analysis and visualisation tool. When the lighting system was turned on, there were no surprises since the results were exactly as shown in the Radiance visualisation.

9.
View from ramps looking out over the central campus.

Fire engineering

Andy Passingham
Tony Lovell

Aims

Arup Fire were commissioned to carry out a study of the North façade atrium enclosure of the building, in particular examining the need for structural fire protection to the exposed steelwork supporting the façade and circulation ramps. The aims driving the study focused on the desire to maintain the clarity and expression of these slender steel elements.

Challenges

The principal challenge this study addressed was the requirements of the New York City Building Code. This states that all structural elements within 20ft (6.1m) of an occupied area should be fire-protected to achieve two hours' fire resistance, irrespective of the actual level of hazard in the space, or its specific geometry.

When the structural elements that constitute the atrium enclosure and ramp supports were considered, it became clear that providing this level of passive fire protection to the structure would not only be extremely expensive, but would also be technically difficult to achieve, particularly on the more slender elements. Conventional methods of achieving this protection would involve either cladding these elements or coating them with cementitious spray-applied material or intumescent paint - all severely compromising the aesthetic goals of the design.

Methods

The fire engineering approach to the project was based on assessing the fire loading that would be expected in the space. It was noted that a code-based provision of fire protection does not specifically address this, as typical fire protection is based on a standard furnace test of an isolated element. This test is therefore somewhat abstract when applied to a real building, as it does not address the location of the structure relative to the likely fire, the influence of the structural frame, or the action of any of the other fire protection systems in the building.

Put simply, a strict code-based approach does not check how long the structure will actually last in a 'real' fire. Arup Fire therefore developed design fire scenarios to simulate the likely fire size and location relative to the structural elements. The effect of the design fire on the structure was assessed by carrying out heat transfer analyses, convective for engulfed elements and radiative for distant elements. The analyses determined the likely temperature of the structural elements in the event of the design fire. This could then be compared to the critical limiting temperature which was calculated for each of the elements based on their inherent properties and design loading.

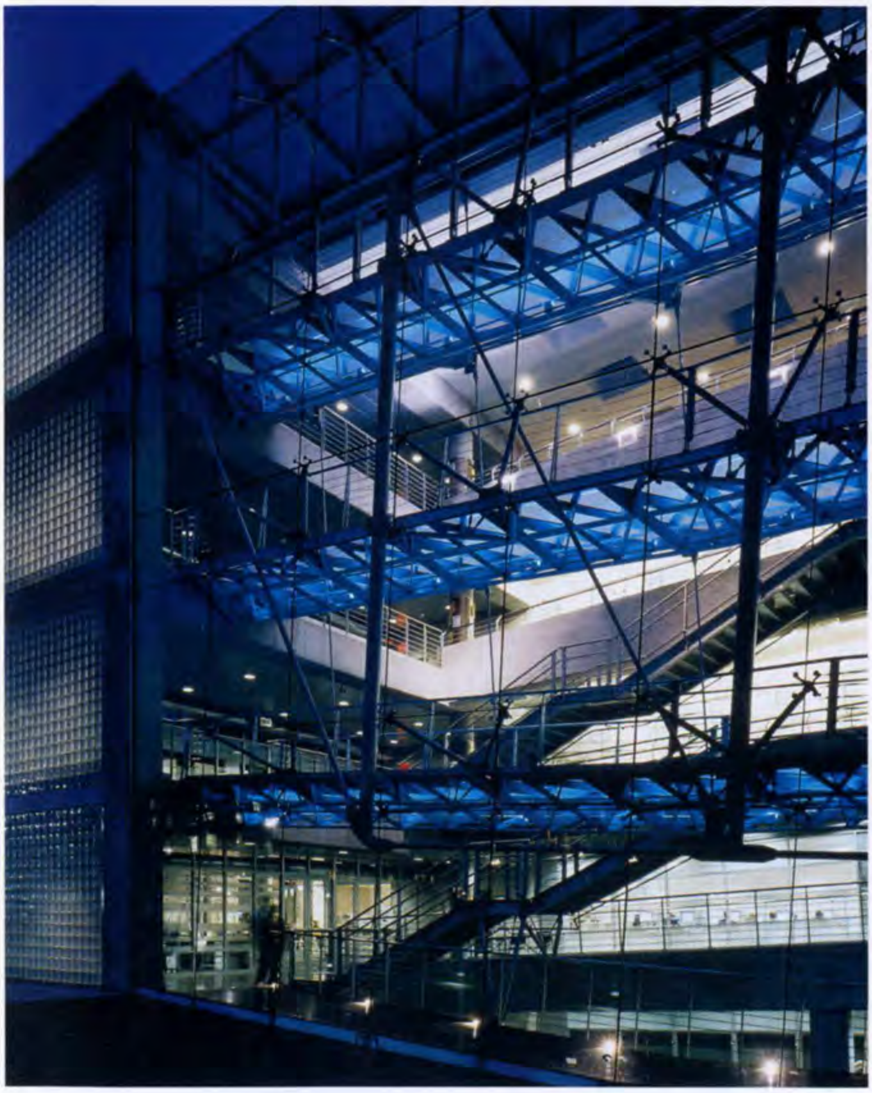
Results of the analyses were that all structural elements remained below their critical limiting temperatures throughout the duration of the design fire. It should be noted here that some of the elements exceeded the commonly accepted 1022°F (550°C) limiting temperature, but were shown to still be below the calculated critical limiting temperature of acceptable structural performance.

Benefits

The analysis was presented to the New York City Borough Commissioners, who subsequently approved the design on the basis of unprotected steel.

This result had several benefits, for several parties:

- The architectural clarity of the structure was preserved, significantly improving the aesthetics of the space.
- A cost saving of $500 000 - $750 000 was achieved, along with reduced maintenance costs for the client.
- The structural scheme could be achieved with greater efficiency, using slender elements.
- A landmark precedence project was agreed with the City of New York, paving the way for advances in the acceptance of alternative fire engineering methods both in the city, and on a wider scale throughout the US.



10.
External view of glass wall ramps at night.

Conclusion

Alfred Lerner Hall is an ambitious design, which required a concerted effort from all members of the design and construction team. The glass wall particularly, with its complex geometry and exposed structure, demanded a closely integrated approach from all of the engineering disciplines - structural, fire, mechanical, and lighting. Only through working together could the scheme have been realised so successfully.

Credits

Client:
Columbia University, New York

Architects:
Bernard Tschumi / Gruzen Samton Associated Architects
Hugh Dutton Associates (glass wall)
RFR (glass wall concept)

Engineers:
Arup Erik Balkey, Burkhard Bein, John Blanchard [*deceased*], Dan Bonardi, Roberto Calalang, Simon Cardwell, Larry Chambers, Varughese Cherian, Bruce Danziger, Graham Dodd, Rey Espiritu, Ian Feltham, Swan Foo, Lou Gargiulo, Marc-Henri Gateau, Graham Gedge, Anne-Sophie Grandguillaume, Matt King, Igor Kitagorsky, Sam Lee, Tony Lovell, Mike MacEntee, John Miller, Chris Murgatroyd, Liam O'Hanlon, Steven Pollard, Ashok Raiji, Mahadev Raman, Joel Ramos, Carleddy Sanon, Joe Saverino, Antony Smith, Marina Solovchuk, Da Teng, Nigel Tonks

Structural engineers (base building):
Severud Associates

Acoustics consultant:
Peter George Associates

Audio-visual consultant:
David Harvey Associates

Construction manager:
Barney Skanska

Glass wall fabricator:
Eiffel Construction Metallique

Glass wall erector:
Precision Specialists

Illustrations:
1, 3, 5, 6: Penny Rees
2, 4, 9-10: Peter Mauss/Esto
7, 8: Matt King

Packaging and transporting nuclear materials

Chi-Fung Tso Patrick Donelan

1.
Train crash demonstration of the Magnox flask.

Introduction

For 20 years, Arup has provided consultancy services to the nuclear industry for packaging and transport of radioactive materials, including design, safety assessment, project planning and project management, risk assessment, and non-linear finite element impact and thermal analysis. Much of the work has brought greater value to clients through improvements in design and development using the latest computer analysis techniques.

Arup's involvement in this industry started in 1980 with a brief from the then Central Electricity Generating Board to demonstrate the safety of the Magnox spent fuel flask in impact. These flasks weigh 50 tonnes and were designed for transporting up to 200 fuel elements from Magnox reactors. The project lasted four years and included extensive drop testing of full-scale and scale model flasks onto 'unyielding' targets and real-life targets, testing of flask components, risk assessment of spent fuel transport, and study of real accident scenarios. It culminated in a spectacular and definitive public demonstration of flask safety - the 100mph crash of a 240 tonne train into a Magnox flask (Fig 1) - with the flask suffering only minor damage and containment intact. And for the first time in Britain, non-linear finite element analysis - then in its infancy - was employed to provide a thorough understanding of the impact behaviour and damage mechanisms. The code used was DYNA3D, and that became the start of Arup's long association with it. The project was the foundation stone of the Advanced Technology Group, from which all Arup's work in this area is carried out.

The design process for complex load cases

In the nuclear industry great importance is attached to safety, so the criteria governing design often include rare events not normally considered in conventional design. These can include low probability accidents (impacts and fires) and rare natural occurrences (tornado-borne missiles, low frequency earthquakes, etc).

This is particularly true when designing containers to package and transport radioactive materials.

In the past, methods to design against these events were not well developed. Designers would use their best judgement and then a prototype would be built and tested. Often a long period of design modification and re-testing followed, delaying overall project completion and pushing up costs; even then, designs only barely met criteria. Projects of this type were thus impossible to plan properly, as time and costs were very unpredictable. Most opportunities to improve a design occur during concept stage; once in detailed design the scope for dramatic improvement is reduced.

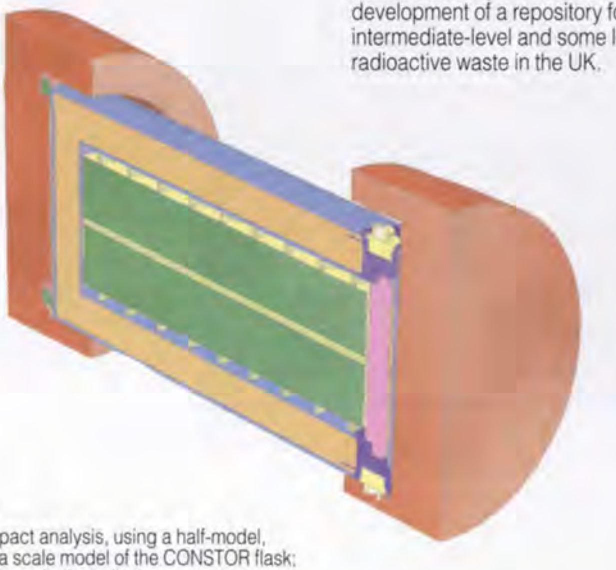
Prototype testing is thus unsatisfactory, as the critical information on whether governing load cases are satisfied or not is only gained after the detailed design is finished. At that stage significant improvements are difficult, and sometimes it is necessary to revisit the concept itself.

With reduction in cost of computers and the rapid development of analysis techniques, this design process has significantly improved.

Even at concept stage, computer analysis of a complex impact or fire event will confirm that the design's performance is adequate.

Any modifications can be quickly re-analysed, so that while still in concept stage an efficient design can be obtained with high confidence that the governing load cases are satisfied.

This article describes several recent Arup projects. They illustrate these points and show the range and diversity of the work undertaken; examples include new designs, assessment and upgrading of existing designs, and research and development projects.



2.
Impact analysis, using a half-model, of a scale model of the CONSTOR flask; colours indicate flask components.

Design projects

Arup has been providing consultancy services to the German flask developer Gesellschaft für Nuklear-Behälter mbH (GNB) since 1998. This has included design safety evaluation of the CONSTOR dual-purpose spent fuel transport / storage flask - analyses as part of a study into optimising its performance, assessment of concrete integrity during normal operational and accidental conditions, and analyses of regulatory 9m drop test scenarios (Fig 2).

A major ongoing project for GNB is the preparation of a Type B license application of a new CASTOR transport flask designed for the Korean utilities. Scope of work includes structural and thermal analyses of the flask for all normal and accident load cases, prediction and assessment of thermal and drop test results, validation of all analyses, and compilation of the relevant parts of the Safety Analysis Report, to the requirements of the US Nuclear Regulatory Commission (US NRC) for certification to Title 10 of the Code of Federal Regulations, Part 71 (10CFR71) 'Packaging and transportation of radioactive materials'.

UK Nirex Ltd was set up by the nuclear industry to co-ordinate the development of a repository for intermediate-level and some low-level radioactive waste in the UK.

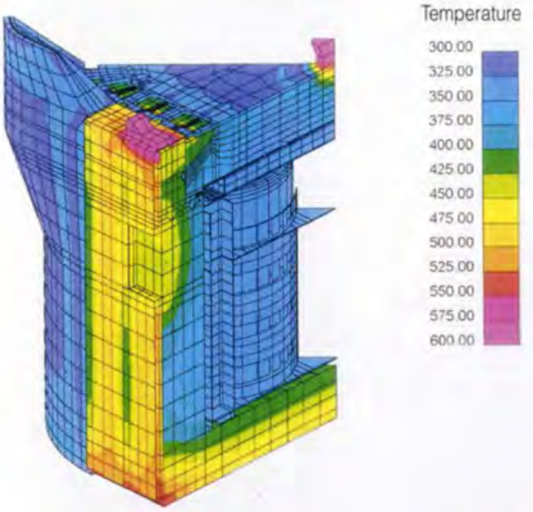
Since Nirex's formation in the early 1980s, Arup has helped with design and development of its standard waste containers and transport containers for these two levels of radioactive waste. Arup developed the Nirex 3m^3 box from the earliest studies of market needs through to concept and detailed design, and prototype manufacture (Fig 3) and testing.

Among the structural load cases for which the box is designed is a 15m drop (representing a handling accident in the repository), following which only a limited amount of radioactive release is permitted. This is the critical design load case. Non-linear dynamic impact analysis was used in all stages of the design - a break with the empirical methods then used in the industry. An early prototype of this container was even successfully drop tested from 40m, illustrating effectiveness of the features designed in to withstand impact.

The box is now being adopted by the UK nuclear industry for the packaging of waste for interim storage and eventual disposal. It is proposed to be used at the Trawsfynydd nuclear power station, North Wales, for packaging decommissioning waste.

When such boxes have to be carried by public transport, they are placed in reusable containers for radiation shielding, containment, and physical protection should an accident occur.

3.
The Nirex 3m^3 box during prototype manufacture.



4.
Finite element thermal analysis (using a $^1/_8$ segment model) of the Nirex re-usable shielded transport container.

Standards for design, manufacture, and operation of containers for transporting radioactive materials are given in the IAEA Transport Regulations[1].

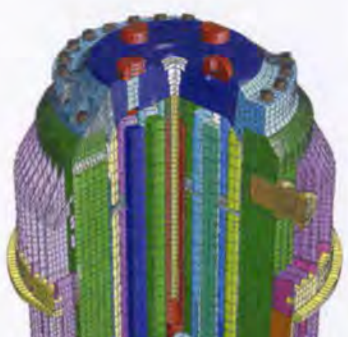
The design requirements vary according to the hazard presented by the material. For spent nuclear fuel (from a reactor), or some intermediate level radioactive waste, the regulations require among other things that the loaded container be able to withstand the cumulative effect of a 9m drop onto an unyielding target, a 1m drop onto a punch, and a 30-minute 800°C fully engulfing fire - all with minimal release of radioactive contents.

These drop test requirements must be satisfied even at the lowest service temperature of the container (typically -40°C).

Nirex transport containers are designed to these standards, and a range is being developed with wall thicknesses between 70-300mm to accommodate the needs of waste with different amounts of external radiation. Arup has carried out concept and detailed design studies for these containers, including prototype manufacturing and testing[2] (Fig 4). The results of both the impact and thermal analyses demonstrate that the release of radioactive material from the container in impact and fire accidents will be below the amount allowed by the Regulations.

Assessing and upgrading existing designs

Arup assisted Rolls-Royce & Associates (now part of Rolls-Royce' Marine Business) in their application for a license from the regulatory authority for their New Module Container (NMC) (Fig 5). It was necessary to demonstrate that the performance criteria in the IAEA Transport Regulations, ie the 9m drop test and the 1m punch test, could be satisfied. In the 'traditional' approach, the critical attitude(s) for drop testing would be selected based on experience and reasoned argument, supported by some finite element simulation.

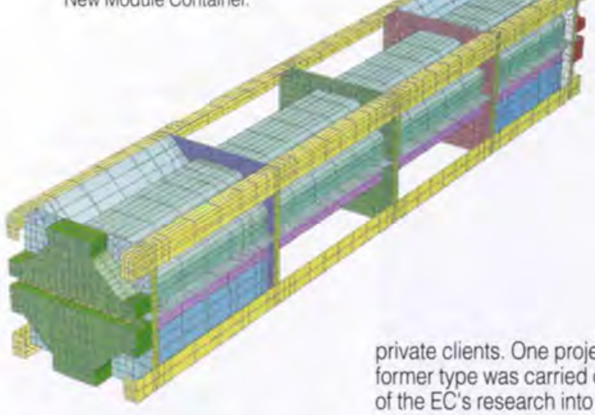


6.
Finite element model of TK-6 spent fuel flask.

However, the NMC was a complex container and there were many potentially critical impact attitudes. Numerous drop test attitudes were analysed using the finite element code DYNA3D, and a small number of scenarios that produced the most significant damage were defined. The performance in these most damaging scenarios were verified by physical drop testing. The DYNA3D predictions were compared with the actual behaviour in the drop tests, which confirmed the accuracy of the analyses[4]. Performance of the NMC in the remaining critical impact configurations was demonstrated by DYNA3D analyses.

As part of the European Commission's TACIS programme (Technical Assistance to the Commonwealth of Independent States), Arup was commissioned to carry out a full safety assessment of the TK-6 spent fuel flask, for compliance with the 1985 edition of the IAEA's Transport Regulations[4]. The TK-6 flask was the first spent fuel flask designed and manufactured in the former Soviet Union during the 1970s. It was designed to carry VVER-440 spent fuel and weighs 90 tonnes.

5.
Finite element model of the New Module Container.



Arup was prime agent for the project, and carried out all impact and thermal and brittle fracture assessments. The sub-contractors were the all-Russian Design and Research Institute of Complex Power Technology (VNIPIET) of St. Petersburg - who gave Arup the necessary information, and carried out parallel calculations - and AEA Technology of Winfrith, who did the criticality, shielding, and containment assessments.

To calculate small displacements (less than 1mm) in the region of the lid-to-body joint of the container during the 9m drop test, it was necessary to build a very detailed computer model, containing over 200 000 elements (Fig 6). The same model was used to analyse performance in both the 9m drop test and the 30-minute fire test.

The results enabled recommendations on how the design and operation of the flask could be modified to satisfy the most up-to-date safety regulations, and were also input to other projects described below: a study of the behaviour of spent fuel containers when impacting real targets, and a risk assessment of spent fuel transport in Russia.

Research and development projects

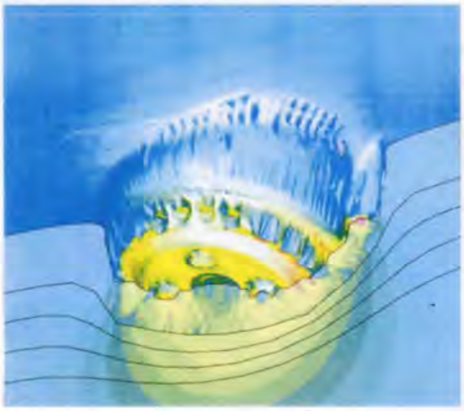
These are either investigations of the adequacy of current regulations carried out for regulatory bodies, or research which will lead to significant cost advantage or improvement for private clients. One project of the former type was carried out as part of the EC's research into the safety of radioactive materials transport. The IAEA Transport Regulations' standard 9m drop test onto an unyielding target is known to be more severe than drops onto real yielding targets such as rock and concrete, etc.

The purpose of the project was to investigate the severity of impacts onto these real targets[5].

Arup's partners were Bundesanstalt für Materialforschung und -prüfung (BAM) of Berlin (the project leader), and GNB of Essen, both of which concentrated on evaluating the performance of containers with 'bolt-on' shock absorbers, while Arup concentrated on containers with 'integral' shock absorbers - ie flasks with geometry at crucial locations shaped for optimum energy absorption characteristics. The results showed that dropping a 90 tonne spent fuel flask from 36m onto 200mm of concrete founded on hard desert soil is far less severe than a drop from 9m onto the IAEA unyielding target. The impact force in the 36m yielding target impact was only 1/4 that of the 9m unyielding target (Fig 7).

The regulations for transport of radioactive materials are stated in deterministic terms, but sometimes it is desirable to assess safety in probabilistic terms, ie the probability of a particular event happening and with what consequences. This type of study, applied to a container meeting the basic IAEA Transport Regulations, reveals what level of safety is really provided by the regulations.

7.
Half-model of the impression on a soil target from a 9m drop of the 90 tonne TK6 flask.



8.
Drop test of a 500 litre drum.

Following the TK-6 flask assessment, a risk assessment of transporting VVER-440 fuel in Russia was carried out for the EC (DG-17). Arup's sub-contractors were again VNIPIET, plus the all-Russian Scientific Institute of Railway Hygiene (VNIIGZH), Moscow, which specialises in railway health and safety. The work assessed risks in transporting spent fuel from the VVER-440 reactor at Novovoronezh to the reprocessing plant at Mayak. VNIIGZH supplied all the necessary rail accident statistics and did route surveys, while VNIPIET assessed accident consequences.

As there have been none to date involving spent fuel transport trains, the statistics used were for normal freight trains. As these are not subject to the same strict controls, this implied a certain conservatism in the results, ie risks were over-estimated.

One interesting study on this project was a probabilistic brittle fracture assessment, which showed that the probability of failure of the flask if dropped onto a real concrete target is smaller than that of a drop onto a yielding target by a factor of at least 3000.

Another project for Nirex evaluated the consequences of dropped load incidents for intermediate level waste (ILW) packages in terms of quantity of activity released. The work included:

- full-scale drop tests on 500 litre drum (Fig 8) and 3m^3 box waste packages filled with inactive wasteform simulants, with test measurements including aerosol measurement, debris particle size analysis, and overall acceleration characteristics
- small-scale drop tests on $^{1}/_{8}$ scale samples of various types of inactive wasteform simulants
- small-scale drop tests on $^{1}/_{8}$ scale samples of fully active wasteforms
- development and benchmarking of finite element impact analyses models of 500 litre drum and 3m^3 waste packages, to allow better understanding of their impact behaviour and for use in future package design developments and assessments
- wind tunnel testing and CFD modelling to investigate the resuspension and spread of released contamination.

The work provided a comprehensive set of activity release data, allowing more accurate assessment of waste packages, and robust construction of transport and operational safety cases.

The validated 500 litre drum and 3m^3 box models have since been used many times as the basis for developing new designs and assessing design variations and improvements of both the 500 litre drum and 3m^3 box packages. Since then, drop tests of another design of a 3m^3 box which had been developed based on these models had been carried out, confirming the performance of the design. The computer model was benchmarked against these tests, and has since been used in further optimisation of the design and assessment of design variations (Fig 9).

Containers for transporting spent fuel and intermediate level waste require thick walls for radiation shielding (300mm or more is not uncommon). Normally these are made of forged steel, reducing the need for welded joints and giving good resistance to brittle fracture even at low temperatures. Over the past decade, however, there has been growing acceptance of ductile cast iron (DCI) for their manufacture, especially in Germany.

9.
Finite element impact analysis of the Nirex 3m^3 box - at the end of a 25m drop.

In DCI the graphite exists in the form of spherical nodules, which aid ductility and resistance to brittle fracture. Other attractions of DCI are lower cost and quicker manufacturing time.

The following project was funded by the Japanese Government (under the STA Fellowship scheme) and the Royal Academy of Engineering (under the Engineering Foresight Scheme), and was aimed at understanding the relationship between the cooling conditions during casting DCI, the resulting microstructure, and the mechanical properties of the casting.

To use DCI for high integrity applications it is necessary to ensure that both the microstructure and mechanical properties at all stages of casting meet specified criteria. However, microstructure depends on cooling conditions, which vary throughout a casting. Also, the mechanical properties depend on the microstructure, so both will vary throughout the casting.

The number of nodules per mm^2 depends on the cooling rate at the solidification temperature - about 1163°C for a typical ferritic DCI casting (but varying with chemical composition). Faster cooling will give more nodules per mm^2. Nodularity is a quantitative measure of how well-formed the nodules are, and the shorter the solidification time the higher the nodularity value. For use in radioactive materials transport containers, a nodularity value of 80% or higher is required, and this can be achieved if solidification during casting takes less than about two hours. When the casting cools down to about 750°C (the actual temperature depends on the chemical composition) the austenite starts to transform to ferrite. Provided that cooling is slow enough at this temperature, transformation to ferrite will be essentially complete before the temperature for transformation to pearlite is reached (about 30° below the temperature for start of the ferrite transformation, depending on the chemical composition). If not, the remaining austenite will turn into pearlite, which gives a more brittle DCI. For use in radioactive materials transport applications, the pearlite quantity must be less than 20%.

This project involved developing a quantitative methodology for calculating the microstructure from the cooling conditions during casting,and calculating the mechanical properties from the microstructure. To verify the methodology, a finite element model of a DCI casting was built and a thermal analysis of the casting process carried out to obtain temperature-time histories throughout the casting. By post-processing the results it was possible to calculate the distribution of nodule count, nodularity, ferrite grain size, percentage ferrite and pearlite, yield stress, UTS, elongation, and fracture toughness.The results agreed well with the measured temperatures, microstructure, and mechanical properties[6].

The Future

There is a growing and varied demand for Arup's services in the nuclear field, even though the industry, in global terms, may have stopped growing in size. This is due to three factors:

- The requirement for packaging for storage and transportation of wastes and spent fuel is rising.
- With the increase in computer analysis capability, Arup can solve problems for clients which previously could not be cost-effectively solved in this way.
- Customers who previously had similar analysis capability in-house find that they cannot keep their skills up-to-date, and prefer to outsource it to firms with this specialist capability.

This trend is expected to continue. For the firm to continue to benefit from it, it is necessary for Arup to keep its skills at the forefront of industry capability.

References

(1) INTERNATIONAL ATOMIC ENERGY AGENCY. Regulations for the Safe Transport of Radioactive Material. IAEA, Vienna, 1996.

(2) SIEVEWRIGHT, RWT, *et al.* Assessment of the sealing system of an ILW transport container in a 9m regulatory impact. PATRAM 98, Paris, May 1998.

(3) EVERETT, D, et al. The benefits of using impact analysis in licensing an industrial package. *International Journal of Radioactive Materials Transport*, *8*(2), pp117-122, 1997.

(4) DONELAN, P, *et al.* Transport of spent VVER-440 fuel using the TK-6 flask. PATRAM 98, Paris, May 1998.

(5) DROSTE, B, *et al.* Evaluation of the safety of casks impacting different types of targets. PATRAM 98, Paris, May 1998.

(6) DONELAN, P. Modelling microstructural and mechanical properties of ferritic ductile cast iron. *Materials Science and Technology*, *16*(3), pp261-269, March 2000.

Credits

Clients:
UK Nirex Ltd
Gesellschaft für Nuklear-Behälter mbH (GNB)
Rolls Royce Marine Power
European Commission DG 17 and DG1A
NAC International
B&W Fuel Company
Eroterv
Paks Nuclear Power Plant Ltd
Nuclear Electric
AWE
BNFL
UKAEA
AEA Technology
Scottish Nuclear

Engineers:
Arup

Project partners:
Bundesanstalt für Materialforschung und -prüfung (BAM)
All-Russian Design and Research Institute of Complex Power Technology (VNIPIET)
All-Russian Scientific Institute of Railway Hygiene (VNIIGZH)

Illustrations
1: CEGB
2: GNB
3, 4: UK Nirex Ltd
5: Rolls Royce
6, 7: European Commission
8, 9: UK Nirex Ltd

Irish racecourse projects

Seamus Mulherin

Beginnings at Cork

In December 1994 the Irish Horseracing Authority (IHA) was established with the mission to reorganise and revitalise the Irish horse racing industry. It took over the role of the Irish Racing Board, which two years earlier had asked Arup's Irish practice to examine the feasibility of redeveloping a small provincial racecourse at Mallow, County Cork, as a Grade 1 track for Cork and the south of Ireland.

The Mallow track is in the flood plain of the River Blackwater and is prone to flooding, mainly in winter - to depths of up to 3m! Nonetheless, Arup confirmed the feasibility of redevelopment, but expressed reservations regarding the flooding and the suitability of the silty turf for very wet or very dry conditions. With this in mind the firm searched the Cork region for a site for a new racecourse, and identified a possible location close to Cork city. At the time, however, it was considered too expensive to purchase and develop.

In 1995 the new IHA purchased Mallow Racecourse, and requested Arup to carry out a more detailed study to identify the measures required to reduce the risk of flooding to an acceptable level, and make the turf more suitable for intensive racing. Following in-depth analysis of the historical incidence of flooding, and selection of a combination of track raising and flood drainage measures, Arup calculated the risk of cancellation due to flooding - for a hypothetical calendar of 14 racedays - to be less than one race day per year. Advice was taken from several specialists about turf drainage and irrigation measures to improve the raceability of the track.

In November 1996, planning and design of the redevelopment of Mallow Racecourse went ahead with Arup as the overall project manager and lead designer, McCarthy Lynch as consultant architect, and PF Coveney (now Bruce Shaw Partnership) as quantity surveyors. The turf specialist design was carried out by Professional Sportsturf Design (NW) Ltd, as a separate consultancy. The IHA wanted the new Cork Racecourse to be state-of-the-art and, with this in mind, the Arup design team with representatives of the IHA visited seven relevant racecourses in the UK: Haydock, Pontefract, Chester, Fontwell, Windsor, Goodwood, and Brighton.

The Mallow upgrading included widening the 2.5km track from 50m to 75m, raising approximately one-third of it by an average of 1m, creating crossfalls on the bends, levelling and re-sodding approximately 60% of the track area, installing land drains across the track at 7.5m centres, regrading the entire infield area to uniform transverse and longitudinal falls, and forming a land drainage / flood drainage collector ditch around the infield perimeter - gravitating to two 900mm diameter flood drainage pipes which outfall with non-return valves to the river.

1 above:
Mallow Racecourse, completed in 1998.

2 below:
Rear of Mallow grandstand.

Developments

In March 1997 the IHA launched a radical plan to invest IR£30M in redevelopment and modernisation of Irish racecourses, principally the eight key courses - Leopardstown, The Curragh, Fairyhouse, Punchestown, Cork, Galway, Listowel, and a new course at Limerick. The IR£30M was to comprise IR£15M from the IHA and IR£15M matching funding from the racecourses themselves.

The investment fund has grown considerably since then, and to date up to IR£70M has been spent or committed to fulfilling the aim of bringing Irish racecourse facilities up to par with other modern leisure and entertainment venues and attracting a new and much wider audience to racing.

Cork Racecourse was the pioneering project of the redevelopment programme and following on from it Arup has either been involved directly in, or has acted as advisor to the IHA on aspects of, most of the other Irish racecourse projects. As well as the eight main racecourses, at least a dozen smaller courses have had various degrees of upgrading.

3.
Listowel grandstand.

4 above:
Galway grandstand.

Arup has generally acted as project manager and/or design team leader, doing the civil, structural and services engineering, with McCarthy Lynch as architectural consultant, Bruce Shaw Partnership as quantity surveyor, and turf specialist support where required. The firm's work has covered more or less all of the elements of racecourse design, including overall layout planning, grandstands, administration buildings, entrances, tracks, jockeys' changing and weigh rooms, parade rings, stables, saddling stalls, car parking, and all the specialist facilities for stewards, judges, tote, bookies, photo finish, press, public address, CCTV, outside broadcasting, and catering.

Since the completion of Cork Racecourse, Arup has been responsible for new grandstands at the Listowel Racecourse (IR£2M), Galway Racecourse (IR£6M), and a new pavilion at Kilbeggan (IR£0.75M). The firm also did the structural design for a new stand at Naas Racecourse.

For the Galway grandstand Arup developed the brief with the client and produced the initial concept design. Before proceeding with the Galway design they visited Cheltenham to see the new Tattersalls Grandstand by Lobb Architects, with its panoramic restaurant.

Galway Racecourse has the most successful festival week in Ireland, with 170 000 punters over seven days. Listowel's festival week is third with 81 000 attendees over six days, whilst Kilbeggan is fifth in the Irish racecourse average attendance league table with 47 000 over six separate summer evening meetings.

Arup recently completed the performance design and procurement for a proposed new track underpass to provide access for cars and buses into the infield car park at Galway racecourse.

Arup's role

As advisors to the IHA on other racecourses, Arup's role has variously included some or all of the following:

- inspecting existing facilities
- making recommendations on development options
- reviewing development proposals and scheme designs and costs
- monitoring project construction costs and certificates
- carrying out site inspections during construction and on completion.

Projects on aspects of which Arup has advised the IHA include major redevelopment at Punchestown and Fairyhouse (IR£8M and IR£7M respectively), expansion and upgrading at the Curragh (IR£4M), a new IR£10M racecourse at Limerick, and various upgrades at a string of small provincial racecourses, including Sligo, Killarney, Tralee, Gowran Park, Wexford, Tramore, Clonmel, Tipperary, Thurles, and Navan.

5 below:
Oil painting by Ray Lyndsay of Kilbeggan new pavilion.

6.
The new Ballydoyle track.

Doing racecourse projects means working with the racing industry, which is particularly wide and steeped in traditions. In Ireland the main bodies involved include the Irish Horseracing Authority and its subsidiary the Tote, The Turf Club (which is the regulatory body for racing and includes the stewards, judges, clerks of courses, photofinish, integrity and head-on cameras), the bookmakers (bookies and betting shops), the Association of Irish Racecourses which represents the racecourse committees and managers, the racecourse committees and managers themselves, the owners and trainers, the jockeys, the outside broadcasting companies, the media (press, radio and television), caterers (bar and food), and last but not least, the spectating public.

The requirements and advice of some or all these bodies and parties have to be taken into account in the design of any racecourse, in whole or in part.

The new Ballydoyle track

In 1998 Arup did the civil engineering and drainage design for a new 1km long by 30m wide grassed training gallop and 6m wide all-weather track at Ballydoyle, one of Ireland's premier racing stables. This was formerly the training establishment of the legendary Dr Vincent O'Brien, and where Aidan O'Brien, one of Ireland's most famous present-day trainers, is now resident. Last year he had one of the most successful strings of two-year olds in Europe, and hopes to do even better this year. In 1999 his *Saffron Walden* won the Irish 2000 Guineas, and recently *Istabraq* won the Cheltenham Champion Hurdle for the third successive year.

Before starting on the Ballydoyle project Arup visited Maryland, USA, with the client to inspect new tracks, including a proprietary all-weather track at the training stables of Michael Dickenson, who as a steeplechase jockey rode five winners at Cheltenham, and as a trainer in 1983 trained the first five horses in the Cheltenham Gold Cup.

Track design is an art in itself, involving the horticulture of grasses and soils, drainage, and civil engineering, combined with the requirements of racing: track layouts, viewing, track widths, bends, cambers, location of finish line, jumps for steeplechase and hurdling, flat racing, six- and seven-furlong straights, and the very particular effects and maintenance implications of horse 'traffic'.

The new Ballydoyle track, apart from the grassing, topsoiling and land drainage aspects, was similar in civil engineering terms to a new roadway.

The initial, 400m, leg of the L-shaped 1km track has a uniform rise of 7m, and the second, 600m, leg has a further uniform rise of 19m. The crossfall was 1 in 60 on the straights and 1 in 30 on the bend. The crossfall on the straights was necessary for surface water run-off but was at the limit of what would be tolerable for horses.

The track construction involved extensive cut-and-fill in the existing boulder clay to achieve the crossfalls and uniform rises, with a maximum 6m depth of fill at the top end. Track drainage consisted of piped land drains across the track at 4m centres, with a collector / french drain along the inside of the track. A 3m wide trainer's road was provided alongside the track.

The track was built in two months, starting in July 1998, with seeding of the grassed track in September and construction of the wood-chipped all-weather track following on over the winter. All the work was carried out by direct labour, under the control of Ballydoyle's project manager and farm manager.

The relative impermeability of boulder clay made it very difficult to work with. It was essential to avoid over-compaction and to keep it as open-textured as possible. Each 0.5m layer was ripped before the next layer was spread. A 300mm depth of topsoil was chosen, partly to compensate for the relative infertility of the boulder-clay subsoil. The grassing and its subsequent maintenance was specified by Mark Gillingham, a UK turf consultant.

A particular difficulty with the hillside site was that it has no natural watercourse to take surface water run-off, and so to balance the acceleration in run-off due to the new track it was necessary to create several terraced holding ponds to limit runoff to its pre-development level. These ponds will provide water for irrigation in the summer. Two irrigation mains were installed, one for the all-weather track - which has to be kept permanently moistened - and one for the grass track.

The all-weather track has been in use since 1999, whilst the grassed track should be ready for use in 2001 or 2002. Currently it is being monitored to see if it needs sand-slitting to ensure it is dry enough for spring training - its main function.

Conclusion

Arup's involvement in the Irish racing industry shows no signs of diminishing. Alongside other ongoing projects, the firm is now - in association with Lobb HOK Architects - preparing a masterplan for the development of Leopardstown, the country's premier racecourse, into one of the world's top racing venues. As well as the upgrading and expansion of the racecourse facilities, the development includes relocation of the six-furlong straight and the stables, necessitated by land take for a proposed new motorway.

Credits

Clients:
Irish Horseracing Authority
(Denis Brosnan, Martin Moore, Tony Corcoran, Noel Ryan [*deceased*])
Cork Racecourse (Michael Lane)
Listowel Racecourse Committee
Kilbeggan Racecourse (Paddy Dunican)
Galway Race Committee (John Moloney)
Ballydoyle Racing Stables

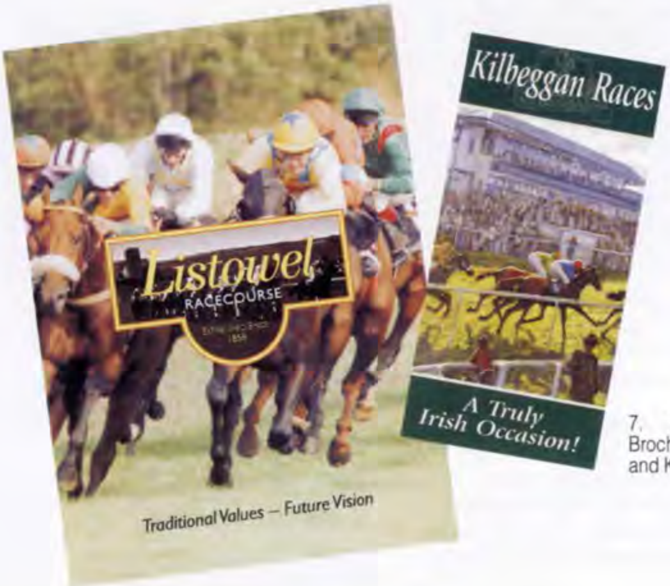
Engineers:
Arup Consulting Engineers Anna-Maria Barry, Lawrence Buckley, John Collins, John Healy, Pat Hegarty, Claire Kelly, Peter Langford, Sinead Mason, Seamus Mulherin, Billy Murphy, Bertie O'Connell, Pat O'Leary, Barry O'Sullivan, Jim Purcell, Ian Roberts, Morgan Sheehy [*deceased*], Jamie Snee, Sean Twohig, Mark Vaughan

Architects:
McCarthy Lynch Architects
(Gerald McCarthy, Trish Leonard)

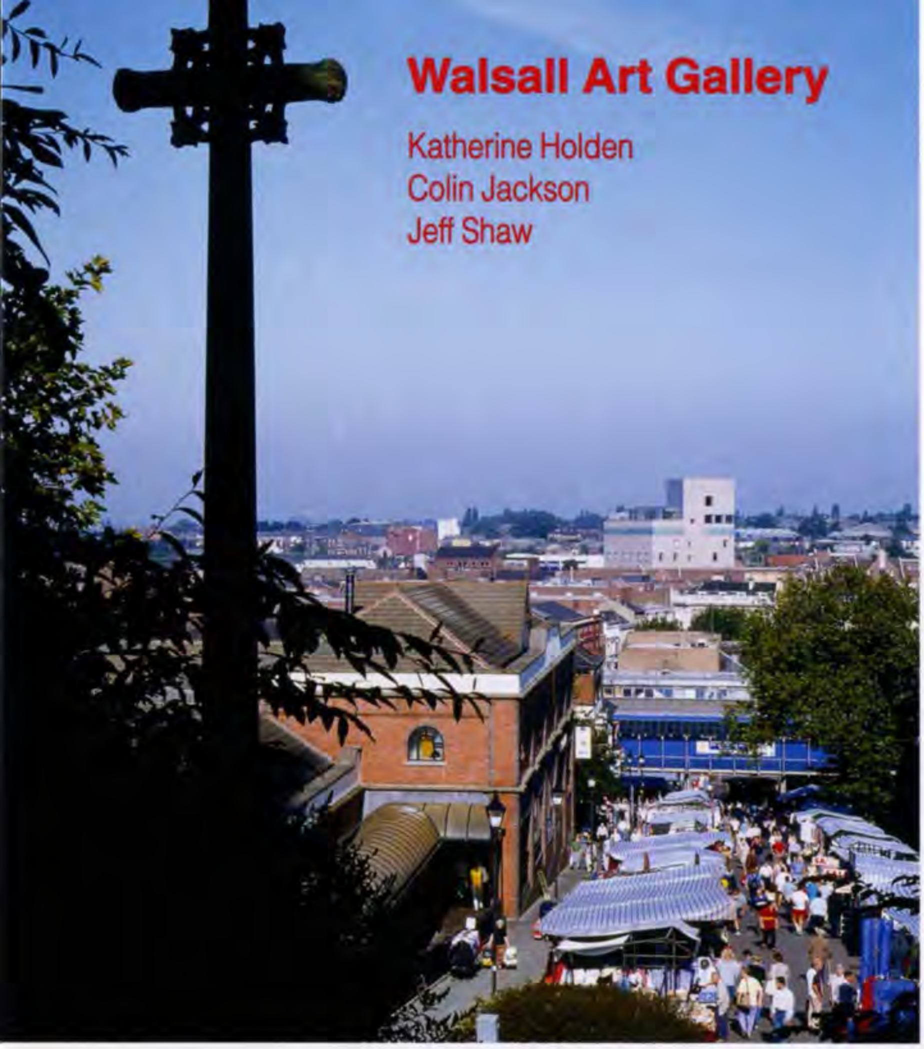
Quantity surveyor:
Bruce Shaw Partnership (Hugh Coveney [*deceased*], Tony O'Regan, Kevin Keogh)

Other consultants:
Professional Sportsturf Design NW Ltd (Mike Harbridge)
Mark Gillingham
Steve Cunningham Associates
(Steve Cunningham, Ciaran Lavery)

Illustrations:
1. Finnbarr O'Connell
2. Barry Mason
3. Seamus Mulherin
4. Healy Photography
5. Courtesy Westmeath County Council
6. Donal O'Callaghan / Penny Rees
7. Courtesy Listowel and Kilbeggan Races.



7.
Brochures for Listowel and Kilbeggan Races.



Walsall Art Gallery

Katherine Holden
Colin Jackson
Jeff Shaw

1.
The Gallery in its urban setting.

Introduction

The new Art Gallery at Walsall - north of Birmingham in the UK West Midlands - not only houses an existing historic collection, but also has world-class facilities for contemporary exhibitions, and interpretation and education spaces.

At the Gallery's core is the Garman Ryan Collection of 350 works by 153 artists, including 43 by the sculptor Sir Jacob Epstein. Kathleen Garman (Lady Epstein), who came from nearby Wednesbury, and American sculptor Sally Ryan - a life-long friend of the Epsteins - created the Garman Ryan Collection between 1959 and 1973 and donated it to the gallery later in the 1970s. As well as those by Epstein himself, particularly bronze statues and busts, the collection contains works by his family, including his son-in-law Lucien Freud, and several by major artists like Picasso, Van Gogh, Matisse, Monet, Manet, Modigliani, Delacroix, Gauguin, Constable, and Turner.

The client, Walsall Metropolitan Borough Council (WMBC), made several attempts to replace the existing Museum and Art Gallery before succeeding with this building. The project was launched by the New Art Gallery Project Director Peter Jenkinson, whose vision and enthusiasm made it succeed, and was based on all-party support from the council and intensive public consultation and marketing. The policy of the new Art Gallery is to exploit both the Garman Ryan Collection and the contemporary exhibitions for their educational potential, and also to explore how contemporary artists can help to interpret the Collection.

The project's total cost was £21M. WMBC had no capital funds itself, so applied for Arts Council National Lottery funding as the best and most ambitious opportunity to provide the new building. £15.75M was forthcoming - covering most of the construction cost - and partnership funding of £4.5M came from the European Regional Development Fund (ERDF), plus £4.426M from Walsall City Challenge for urban regeneration. To secure the ERDF funding, the contract was let in two parts. The main contract had to be let by the end of December 1996, with provisional sums for the services and other contracts. Construction began in January 1997.

The architects were Caruso St John Architects, a small practice based in London. Their concept was of a 'big house' with irregular window layouts, and clad in terracotta. Located near the top of a pedestrian shopping street, by a canal, it is five large storeys tall, mirroring in height a church at the other end of the town (Fig 1).

2.
Timber cladding with boardmarking above.

The Garman Ryan galleries are small in scale, to suit the size of the works in the Collection, but the exhibition galleries are large and are lit with clerestorey windows. The 'Children's House' contains a discovery gallery, education rooms, and an artist's studio; adjacent is the art library, and there is also a public research room. On the top floor a conference room, restaurant, and winter garden all have splendid views over the town and surrounding area. The back-of-house has staff offices, art storage, and a workshop.

Structure

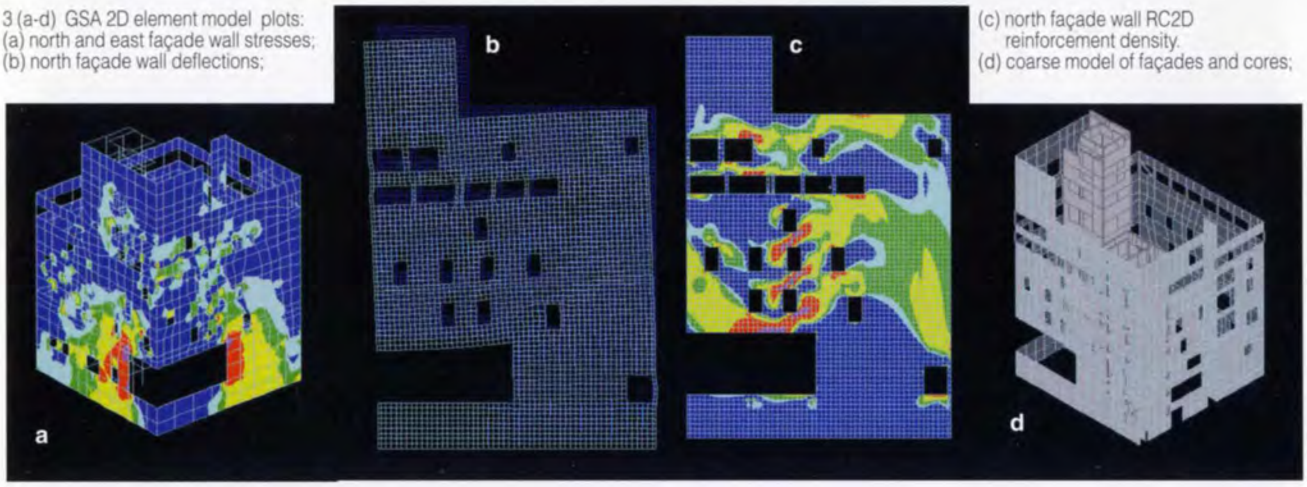
The building has a gross area of about 5200m^2. The structure is entirely of reinforced concrete - a mixture of in situ and precast. Ribbed floors are supported by internal and perimeter walls at lower levels (first-third) and by beam / column frames and perimeter walls above (fourth level and roof). The ground floor is entirely column-free. There is a single-level, externally tanked basement for art storage and plantrooms. Shallow foundations bear directly on Silurian limestone.

Gallery floor loadings are generally at the statutory minimum of 4kN/m^2. This is adequate for most purposes, but it restricts the siting of heavy sculptures, and greater loading capacity was required for the third floor temporary exhibition space and some circulation areas. The study of loading levels required to provide this flexibility was one example of the co-operation between the clients and design teams for Walsall Art Gallery and the Tate Modern at Bankside. The Tate provided details of the weight and footprint of several heavy sculptures that the Walsall Art Gallery wished to be able to accommodate. These included Epstein's *'Jacob and the Angel'* (2.5 tonnes on a 1m^2 base) and Hirst's *'Mother and Child, Divided'* (14 tonnes on an 8m^2 base). A loading allowance of 10kN/m^2 for display areas and art movement routes to them provided the desired flexibility for siting the sculptures identified.

The exterior is fully clad, for the most part in terracotta tiles, but with stainless steel between ground and first floors and on the inward-facing walls of the tower which projects above roof level on the north east corner. Inside the building, wall linings are typically stopped short at high level to reveal a boardmarked concrete finish (Fig 2). The wall linings are 75mm wide Douglas fir boards - the same timber and width used for the board-marked concrete wall formwork, giving the illusion that the in situ walls were poured into the linings which were then peeled back to reveal the board marks. Pre-tender samples of the boardmarked concrete finish were made to define the quality required and to test the prescriptive specification which was based on a survey of experience from the 1960s and 1970s when similar finishes were popular.

The form of the structure was largely determined by several features of the building:

- The large rectangular gallery spaces with exposed concrete ceilings suggested the precast ribbed floor. The timber joist analogy precluded the use of tapered sides for the ribs, so they were precast individually in sprung steel forms which, when released, enabled the rib to be withdrawn upwards. This analogy also dictated the aspect ratio of the ribs, which led to the narrow, 120mm, width. An interesting, if structurally illogical, feature of the ribbed floors is that the depth of the ribs relate not to the loading and span of the floor, but to the floor-to-ceiling height of the space below. Thus the temporary exhibition floor supporting the heaviest loadings over spans up to 10m has the shallowest ribs, due to the fact that the second floor houses part of the Garman Ryan Collection and is therefore a modest (for this building) 4.5m floor to floor. The slenderness of the ribs led to several precast concrete contractors declining to tender due to perceived difficulties in transporting them to site undamaged.



3 (a-d) GSA 2D element model plots:
(a) north and east façade wall stresses;
(b) north façade wall deflections;
(c) north façade wall RC2D reinforcement density.
(d) coarse model of façades and cores;

This did not prove a problem for the successful tenderer who transported the ribs to site upright on bearers and separated from its neighbours by padding. Precast soffit panels, incorporating holes for lighting and other services, span between the ribs. These provide permanent formwork to the in situ slab forming the table of the T-section and the horizontal diaphragm which transfers lateral forces to the perimeter walls.

- The column-free ground floor is realised by transferring all loads from above to the perimeter walls. This is achieved by using the internal walls of the Garman Ryan galleries as transfer beams.

The Garman Ryan floor plan is similar on the two levels occupied. The walls, which span up to 18m, are therefore 9m deep (2 x 4.5m). Door openings are accommodated, at similar locations on the two levels. A consequence of the transfer of load to the perimeter is that little downward load remains on the basement slab away from the edges to counteract the upward water pressure on the underside of the basement. Although the permanent water table is close to basement level, the proximity of the canal basin means that should a breach occur in the puddle clay lining to the basin, water may possibly rise to close to ground level around the building. To hold the basement slab down in this event, ground anchors grouted into the limestone below have been installed on a 3m grid.

- The architects introduced the concept of a landscaped 'Gallery Square' flowing into the building. However, this could only be realised if a significant length of façade wall was omitted between ground and first floors at the main entrance in the north-east corner of the building. On the north façade these walls are omitted for 13m - half the length of the building - and for 6.5m on the east façade. The façade walls above first floor cantilever over this opening to transfer forces to the walls that continue to the foundations. The design of the walls to perform this function was complicated by the irregular pattern of window openings and the need to support the double-storey height transfer beams which span over the ground floor.

To analyse and design the reinforced concrete internal and façade walls, 2D finite element models were analysed using Arup's in-house structural analysis package GSA (Fig 3). The results of these analyses were then post-processed to produce arrangements of reinforcement.

The post-processor, RC2D, was written by Arup Research & Development and has since been incorporated into GSA as a standard feature. The program uses a procedure based on the Wood-Armer method devised for bending elements and widely used for floor slabs and raft foundations.

Lighting

The lighting was a major focus of the design from the outset. It was decided early on that a significant component of the gallery lighting would be natural daylight, and that it would be from the sides. The decision to side-light was partly sheer necessity, due to the large gallery area stacked up on the small site which eliminated the possibility of using skylights. However, this approach also suited the 'domestic' quality desired of some of the gallery spaces housing the Garman Ryan Collection (Fig 4). The challenge was to make side-lighting work for both this and the Temporary Exhibition galleries, which required quite different lighting conditions.

4.
Garman Ryan Collection gallery space.

5.
Temporary Exhibition.

6.
Computer-generated graphic of Temporary Exhibition gallery

An important consideration in side-lit spaces is that light from the horizon is only a third as bright as light from the zenith - the sky directly overhead. Additionally, side-lit spaces are prone to producing asymmetric lighting conditions, and can cause reflections on artworks hung opposite that hinder their viewing.

The Garman Ryan Collection is arranged by theme rather than by artist or period, and so each room contains works in various media, each requiring different lighting levels for conservation reasons. By placing windows off-centre in these rooms, the asymmetric characteristics of side-lighting are emphasised, allowing works in oils which can be hung on brightly lit walls to be in the same space as paper-based works which must be exposed to considerably less light.

To arrive at the most suitable balance of light and dark in these galleries, the design team studied the curators' requirements in depth, and determined that a window reveal depth of 600mm, together with metal sputtering on the window glass, would give suitable light distribution and diffusion. The quantity of available daylight varies considerably over the course of a day, and through the year. White material blinds with a light transmission value of 10% provide additional control of the amount of daylight entering the space, and are lowered when the daylight levels exceed a set limit or when direct sunlight shines on the windows.

In the Garman Ryan galleries, the lighting levels were designed using a kilolux-hour per year approach for the exposure of the artwork to light. This takes into account the cumulative exposure throughout the year, rather than targeting a specific constant lighting level to be maintained at all times. This permits short-term variation in the levels of light, enabling the design approach to accommodate some natural variations in light levels.

The artificial lighting in these spaces is also located off-centre, and its design was influenced by the natural lighting strategy. Large suspended diffuse-glass boxes called 'laylights', containing fluorescent luminaires and conceived as sculptural ceiling furniture by the architects, provide ambient lighting when daylight is insufficient. The light levels can be dimmed or raised automatically to respond to daylight levels, and connections for spotlights are provided from tracks concealed within each light box to highlight specific works.

The main Temporary Exhibition room is the largest in the UK after the Tate Modern at Bankside, and is naturally lit from three sides. The lighting levels throughout the Temporary Exhibition rooms are strictly controlled to meet the requirements of international art lending institutions by using a layered clerestory window system (Figs 5-6). Electric lighting and motorised blinds, together with heating and ventilation services, are located in the cavity between light-diffusing layers of glass. The blinds adjust constantly yet discreetly to ensure that the permitted light levels are not exceeded, and the electric lighting is automatically dimmed to supplement daylight when required and to illuminate the spaces at night.

Whereas asymmetric lighting was desirable for the permanent collection, the Temporary Exhibition rooms require even levels of light. The diffusing window glass and height of the rooms allows for intra-reflections within each room, ensuring largely uniform light levels on the walls. As the windows are located above eyebrow level the risk of reflections is also eliminated.

Mechanical services

The mechanical services brief for the galleries was that the internal air conditions should be of international standard, so that works of art could be borrowed from all over the world. This meant that they had to be air-conditioned, with close temperature and humidity control, and a study was made of existing galleries and conditions recommended by art experts to determine what was appropriate. Pollution data for the area were gathered, as levels of acidic gases like sulphur dioxide had to be kept very low - typically 20-50 times less than outside. Activated carbon filters were used to remove almost all the acidic gases.

The design noise level is NR30 for the galleries and conference room, which also is air-conditioned, with comfort cooling. The remainder of the building, however, is naturally ventilated where possible, both to save energy and to achieve relative simplicity. In some of the public areas, high-level motorised vents are used instead of windows, both from architectural preference and because of concerns about people falling out of windows. The basement, toilets, and kitchen are all mechanically ventilated.

The services had to be carefully integrated with the architecture and the structure, because the building is very irregular and does not have many accessible false ceilings or floors. There are two main risers, but they are blocked off from the main floors in some areas by double-height spaces or stairs, making it necessary sometimes to take the services through tortuous routes which during the design had to be visualised in 3D.

Architectural acoustics

Richard Cowell

The substantial building envelope construction, with sound insulating glazing, protects the interior from a moderately noisy external exposure (in the range 60-70dB LAeq).

When combined with building services noise controls, this achieves sufficient restraint over noise to avoid significant aural distraction.

The Gallery acoustic design balances the necessary control of reverberation - to limit activity noise and help public address intelligibility - with the creation of an aural sense of the space.

Visits were made to the existing Walsall gallery and others, including the Tate Millbank and Lisson Galleries in London. Reference was made to a wide range of previous gallery studies to refine the targets for reverberation control. Auralisation of the effects of reverberation on speech intelligibility was also arranged.

Mid-frequency reverberation time maximum targets in the range 1.2 - 1.8 seconds were set. The openings between galleries and the design preference to avoid unnecessary 'soft' finishes challenged the scope to restrain reverberation. Materials selected for visual hardness with effective sound absorption were integrated into the finishes at high level.

9.
Entrance foyer.

Where there are exposed concrete ribbed ceilings, air is distributed within thick walls, from below or from risers at the sides (Fig 7).

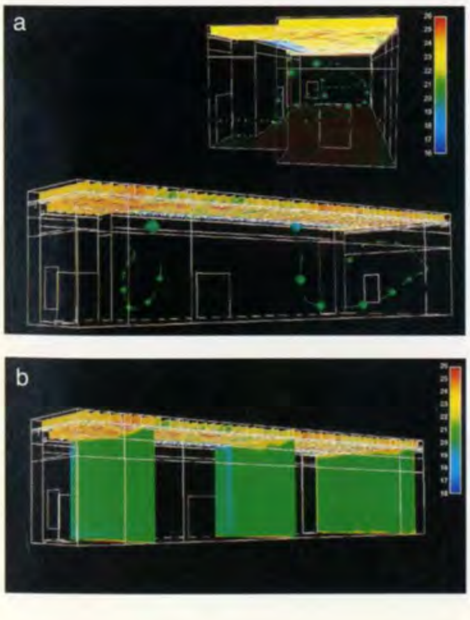
The architects wanted to have virtually invisible services. In the Garman Ryan galleries, the air is supplied at the top of the laylights suspended just below the wooden ceiling. The return air is extracted through slots in this ceiling. In the Temporary Exhibition galleries, air is supplied from long slots at the tops of the walls and extracted through the clerestorey windows.

7.
Air-conditioning ductwork
being concealed behind thick walls.

8.
CFD models of Temporary Exhibition gallery:

(a) Summer air movements with temperatures in °C.

(b) Vertical sections showing summer air temperature distribution in °C.



This both helps to remove some of the heat that builds up in these windows and reduces solar gain to the rooms. Computational fluid dynamics (CFD) was used to model air distribution in a key gallery, to check that it would mix properly (Fig 8). In the Children's House rooms and the conference room, air is supplied and extracted through long slots at the tops of the walls.

The air systems for the galleries are all-air, mixed ventilation, with high-level supply and extract. The air-handling units (AHUs) are constant volume with zonal reheat and rehumidification. They have minimum outside air - between 20% for one unit and 45% for another - as the client wanted to keep the carbon filters as small as possible. These have to be replaced every two to five years, depending on outside pollution and extent of use, and they are quite expensive. All the AHUs have heat recovery. Most of the air plant is in the basement. There are air-cooled chillers, two AHUs, a generator on the roof tower, and boilers within the tower.

A stair pressurisation system was required because one set of stairs was not located on the outside of the building and there was not a spare escape stair, which could be discounted. It was difficult to integrate this system into the building, as it requires a lot of plant and riser space, and available vents from the floors were limited.

There is a sophisticated building management system to operate the services systems efficiently and monitor conditions. The predicted annual energy use is approximately 170kWh/m^2 in total: 35kWh/m^2 of gas and 135kWh/m^2 of electricity. The main uses of energy are for the lights and the fans. Since the air-conditioning system has been running, once a few hitches had been sorted out, the measured temperature and humidities have been within tolerance and very stable. The systems are also very quiet.

10 right:
Gallery exterior.

Conclusion

The new Gallery was completed within budget in February 2000, and officially opened by HM The Queen on 5 May. The client's aims were achieved: an outstanding building worthy of visiting for its own sake, and the best and most accessible accommodation for the Collection, the temporary exhibitions, and the education programme. Structure and services were carefully integrated to satisfy the challenging demands of the brief and the architecture. The building has since been acclaimed in many national and local newspapers and in the architectural press.

Credits

Client:
Walsall Metropolitan Borough Council

Architect:
Caruso St John Architects

Engineers:
Arup Peter Bailey, Tony Campbell, Ed Clark, Stuart Cowan, Richard Cowell, David Gilpin, David Glover, Simon Hancock, John Heath, Judith Henson, Katherine Holden, Colin Jackson, Adam Jaworski, Barry Jefcoate, Lidia Johnson, Jon McCarthy, Alan Reading, Sharon Rose, Andy Sedgwick, Jeff Shaw, Ned Stork, Malcolm Turpin, Paula Walsh, Colin Whewell

Quantity surveyor:
Hanscomb

Project managers:
The London Group (pre-contract)
Bucknall Austin [now Citex Project Delivery] (post-contract)

Main contractor:
Sir Robert McAlpine

Concrete subcontractor:
Code

Services subcontractor:
Drake & Scull

Illustrations:
1, 2: Hélène Binet
3: Ed Clark
4, 5, 9, 10: Paul McMullin
6, 8: Darren Woolf
7: Peter Mackinven

Printed in England by Reedprint Limited, Windsor, Berkshire