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Front cover:
The amenity building at the new Inland Revenue Centre, Nottingham
(Photo: Graham Gaunt)

Back cover:
Part elevation of Lille Grand Palais, outside the entrance to Congrès, with Expo beyond (Photo: Peter Mackinven)

Newcastle Quayside infrastructure
Martin Butterworth
David Stevens

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A 10-year regeneration programme is under way for some 30km of derelict land along the banks of the Tyne and Wear. One 20ha site near Newcastle upon Tyne city centre has been singled out for priority treatment, and Arups' Newcastle office has been involved for the last six years in extensive civil engineering infrastructure work, including rebuilding the 19th century quay-wall, remodelling terrain for the architectural masterplan, and installing new roads, drainage and services, as well as provision of new multi-storey car parks.

Sandton Library, Johannesburg
Craig Thompson

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This 85 000-volume public library forms part of a new commercial and civic centre for Sandton, on the outskirts of Johannesburg. As well as being responsible for the geotechnical and civil engineering, Ove Arup Incorporated designed the building's structure, the most notable aspect of which is the suspended steel spiral ramp that encircles the interior of the central atrium, linking the various levels of the library.

The new Inland Revenue Centre, Nottingham
John Berry, James Bown,
John Thornton, John Turzynski,
Martin Walton

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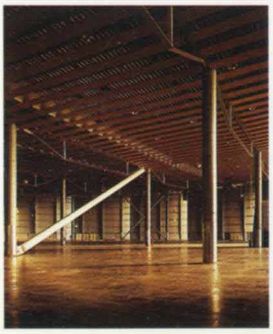
Arups' building engineering design for the new Inland Revenue HQ was driven by a desire to integrate completely the architecture, structural, and environmental concepts. The brick and precast concrete structure, repeated in all the office buildings, incorporates a natural ventilation system that dealt successfully with the summer 1995 heatwave, whilst the lightweight fabric roof to the amenity building allows a high degree of natural lighting.

Lille Grand Palais/ Zenith/Congrès/Expo
Rory McGowan, Robert Pugh



18

Arups designed the structure and concept services for this entertainment, conference, and exhibition centre at Euralille. The huge egg-shaped structure embraces three buildings in one: Zenith, a 5000-seat rock concert hall/convention centre; Congrès, a 20 000m² five-floor conference centre which includes three lecture theatres, 12 meeting rooms, a banqueting suite, exhibition spaces, and administration accommodation; and Expo, an exhibition centre covering a further 20 000m² that can be subdivided into three separate halls.

Newcastle Quayside infrastructure

Martin Butterworth David Stevens

1. Farrell Masterplan.

Introduction

Following an Act of Parliament in late 1987, the Tyne and Wear Development Corporation (TWDC) was formed with the main purpose of regenerating, over a 10-year lifespan, approximately 2430ha of derelict land stretching some 30km along the banks of the Rivers Tyne and Wear.

One of the Tyneside sites is within a stone's throw of Newcastle upon Tyne city centre and, because of its prominent location, was identified as a 'flagship' by the Development Corporation. Known as Newcastle Quayside, it was to be developed for select offices, leisure, and high quality housing. In mid-1988 TWDC invited developers to put forward proposals, and in early 1989 Newcastle Quayside Development Ltd (NQD) gained 'preferred developer' status. Amongst the design team engaged by NQD were Ove Arup & Partners as consultant structural engineers. As part of the development agreement TWDC agreed to provide and finance all the civil engineering reclamation and infrastructure for the site. Since Arups were already identified as consulting engineers to the developer, to ensure no conflict of interest TWDC negotiated a direct separate appointment with Arups' for the design of the civil engineering reclamation and infrastructure. As a result of problems associated with land purchase (resulting in a subsequent Compulsory Purchase Order inquiry), change of ownership in NQD, and development of the masterplan for the site, construction of the civil engineering reclamation and infrastructure only began on site in April 1992. These works will essentially be complete by mid-1997.

History

Historically, this riverside area has played an important part in the development of Newcastle upon Tyne, particularly for the export of coal to other parts of the UK as well as further afield. During the late 15th and early 16th centuries, extensive dumping occurred here of ships' ballast from barges, which were then filled with coal for their return journey. After 1850, Tyneside grew rapidly; there was a marked increase in shipping, resulting in deepwater quaywalls being built on the River along the length of the Quayside site. In 1849, however, the Stephenson High Level Bridge linking Gateshead to Newcastle had been built, and this gave people the opportunity to cross from one conurbation to the other without having to descend to the banks of the Tyne. Local historians believe that the advent of this single structure resulted in the local population turning their backs on the quayside, and although it continued to be a busy area for shipping and commerce, once the decline and redeployment of exports commenced it began to run down until the present day when it became part of the TWDC's area for regeneration.

The site and development philosophy

The site lies on the north bank (Fig.2), about 1km downstream of the famous arched Tyne Bridge, built some 80 years after the High Level Bridge. It runs along about 1km of the river bank, extending some 200m to its northern boundary at City Road. Eastwards it is bordered by the Ouseburn, a tributary of the Tyne, and westwards by the Crown Courts (another Arups' project). Newcastle Quayside can be divided into three distinct parts: the lower plateau that lies between a former road - itself named the Quayside - and the River; the upper plateau which forms a thin strip of land to the south of City Road; and finally the steep slopes of the river valley that lie between the two plateaus. The lower plateau is at about 4m OD whereas the upper part of the site varies in level between 20m OD to the west and 23m OD to the east.

Farrell and Partners (formerly Terry Farrell and Company) were appointed as masterplan architect, and the Farrell Masterplan, as it became known (Figs.1 & 3), envisaged a row of office blocks along the quay edge, pub/restaurants in the main square, multi-storey car parks set into the steep slopes between the upper and lower plateaus, and a hotel and housing development at the eastern end near the Ouseburn.

2. The site.

3. 1992 model of Farrell proposals.

For the Farrell Masterplan to be realised, significant civil engineering infrastructure to the value of £40M was needed (Fig.9), and this has included:

- refurbishment and reconstruction of the quaywall on the banks of the Tyne
- significant earthworks and construction of retaining walls to create further plateaus needed for development
- demolition of numerous structures except for two historically notable buildings: the Cooperative Wholesale Society Warehouse, built in 1901 and now a Grade II listed structure; and the Sailors Bethel, a seamen's mission and chapel constructed in 1877. The latter has been refurbished and the former will be, as part of the development.
- Installation of new roads, drainage and services including hard landscaping of public areas, access routes and squares
- provision of the multi-storey car parks.

The construction programme for these infrastructure works was geared to the release of developable plots of land in line with the Development Agreement between the TWDC and NQD.

The civil engineering infrastructure

The quaywall

The quaywall along the river frontage was constructed in phases between 1840 and 1893, and various sections required repair or reconstruction. Repairs have been carried out over significant lengths of wall and include replacement of cracked and damaged masonry with material similar to the ashlar facing; pressure pointing to the bed and perpend joints; and stitching and grouting of significant cracks. The wall height along its entire length has been raised to 4.5m OD to reduce the risk of flooding due to global warming. This has been achieved by removing the granite coping stones, building up the existing wall with ashlar masonry, and then replacing the coping. In those areas where the granite copings were damaged these have been replaced by precast concrete ones.

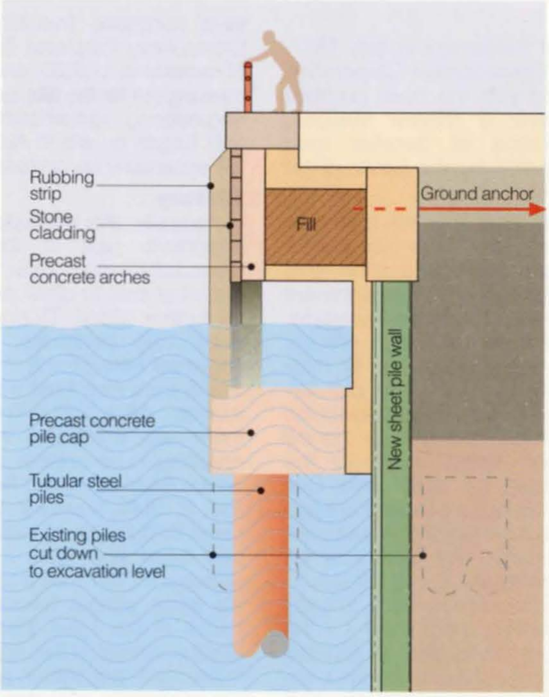
Major reconstruction of the walls was necessary at two locations. The first, of approximately 70m length, occurred where an existing timber infill jetty was removed and replaced by a new length of quaywall. A new high modulus anchored sheet piled wall was constructed along the face of the quay and backfilled. The infill section has ashlar facing in stone coursed to match the existing adjacent walls. The second major reconstruction occurred at the eastern end of the site, where 260m of existing quaywall had to be replaced. Various schemes were costed and discussed with the TWDC - including refurbishment options - but the condition of the existing wall and its cast iron caisson supports (Fig.4), together with the fact that four-storey residential blocks were to be built approximately 10m from the quay edge, dictated a complete rebuild. A major planning constraint was that the arched appearance of the existing wall had to be retained. This has been achieved by threading a high modulus sheet pile wall in between the existing caissons (Fig.8), which in turn is connected to the anchor wall with tie rods. The design of the wall was complicated by the interaction between the high modulus sheet and anchor walls, due to their proximity because of space restrictions. This necessitated a detailed finite element analysis, using Arups' SAFE program, to assess stability and movement.

The high modulus wall is set back from the original line of the quay wall to enable a new arched facing to be constructed in front, thus maintaining the original appearance and satisfying the planning requirements.

4.
Quaywall - existing structure, February 1993.

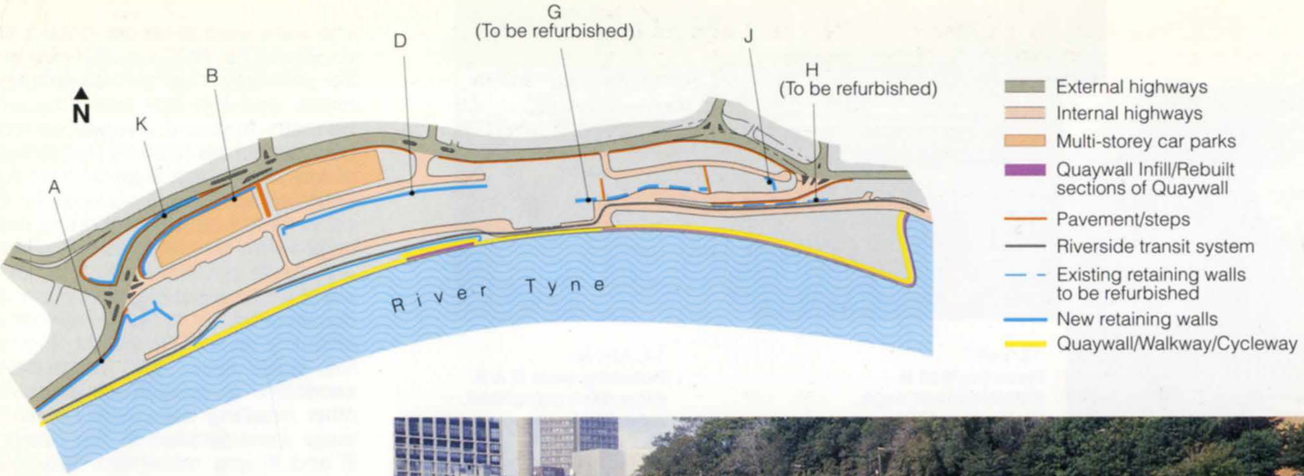
5. Left:
Quaywall demolition, April 1994.

6. Left:
Precast stone-clad arched panel, June 1994.



8.
Cross-section through quaywall.

7.
Precast arched panels lifted into position onto precast pilecaps, February 1995.



9. Plan of civil engineering infrastructure, showing retaining walls A, K, B, D, G, J and H.

The facing system was designed to enable precast units to be lifted into position and tied into the main structure, so as to limit works in the tidal zone (Figs.5-7). A series of arched precast wall panels faced with reclaimed stone were lifted onto precast concrete pile caps supported on tubular steel piles. The new facing was constructed along the original line of the quaywall, with the new piles offset by half a bay to avoid a clash with the existing caissons. All the stonework used for facing was reclaimed during demolition of the old quaywall and sawcut on site to meet the required 200mm thickness.

All of the quaywall has been provided with new handrailing and furniture including lighting, mooring bollards, access ladders and timber rubbing strips (Fig.10), some of which used timber reclaimed from the old infill jetty.

Retaining walls

Fig. 9 shows the location of various retaining walls across the site. These have included diaphragm construction and anchored contiguous bored piles, as well as the more traditional reinforced concrete cantilevered stem walls. The more technically challenging of the walls were:

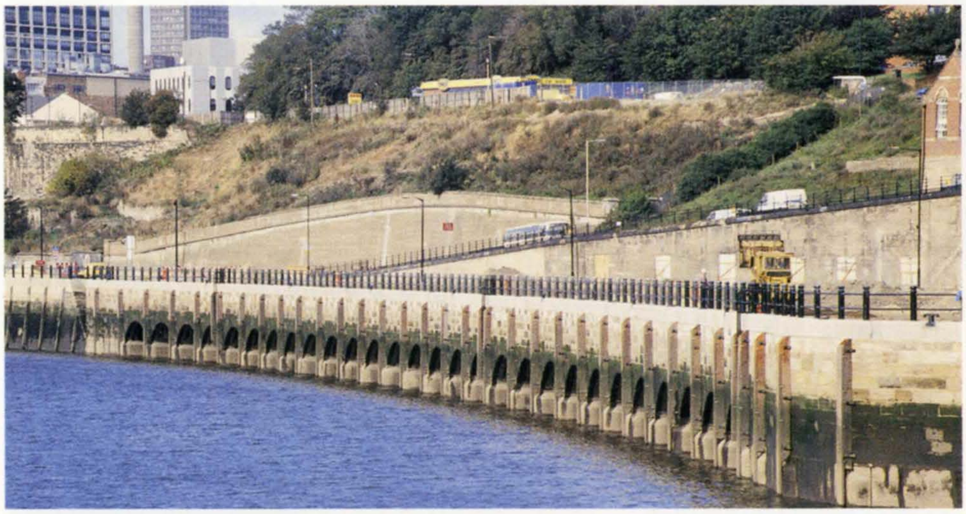
Retaining wall A

Rising to a maximum height of 5m, wall A was constructed at the western end of the site to separate the public highway from the lower quayside plateau. During the ground investigation, both the medieval town wall and the quayside main interceptor sewer were located, running parallel to each other and on the exact line of the new wall. Obviously both structures had to be protected, so a design solution for the new wall was devised in which bored, cased piles were installed either side of the medieval wall and interceptor sewer, and bridge beams placed between the piles (Fig.11).

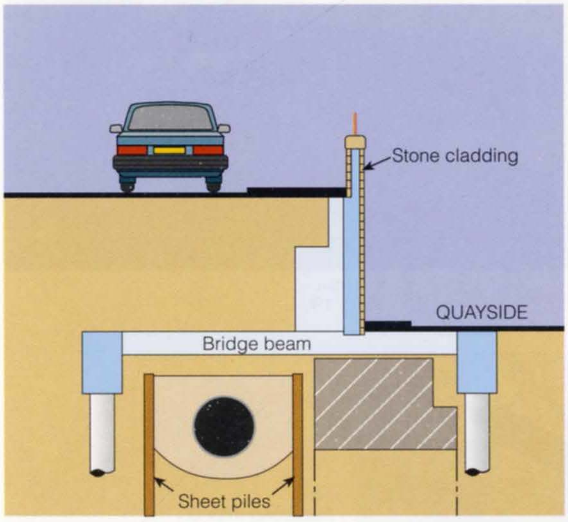
The beams then supported the cantilevered stem of the new wall, which was designed to span perpendicular to the bridge beams. This choice of construction was readily accepted by local historians and archaeologists as a sensible solution, and by Newcastle City Council (NCC) who were ultimately to adopt the structure. The wall has been faced with natural sandstone and sandstone copings to emulate the traditional use of natural materials in this area of the quayside (Fig.12).

Retaining walls B and K

These walls were constructed parallel to each other on the northern boundary of the site to accommodate the realigned highway. The northern wall (K) supports the difference in level between City Road and the realigned highway, whereas wall B supports the realigned highway above the plateau which forms the site where the Phase 1 multi-storey car park was subsequently constructed.



10. Above:
Rebuilt quaywall,
September 1995.



11. Left
Cross-section
of retaining wall A.

12. Below:
Completed retaining wall A,
September 1993.

13. Left:
Retaining wall B -
Reinforcement cage,
September 1993

14. Above:
Retaining walls B & K -
excavation completed,
June 1994.

15. Below:
Retaining wall K completed,
September 1995.

The walls were to be designated as highway structures by NCC who did not want them to be anchored due to maintenance requirements and the fact that they would pass beneath adjacent properties outside the boundary of the highway, requiring a number of way leaves, etc. Support from the car park structure was also unacceptable. This resulted in them being designed as freestanding cantilevers, with consequent effects on size and depth of embedment (Fig.13). The walls are of reinforced concrete T-panel diaphragm construction, up to 30m in overall depth and retaining up to 12m height (Fig.14). Wall K has been faced with rough-hewn natural sandstone to provide visual continuity with other retaining walls in this area (Fig.15). A major consideration in the design of walls B and K was movement. City Road has a number of services buried beneath it, in particular two old high pressure 30in (760mm) cast iron water mains. Discussions with the water authority established that these could not tolerate any movement. A detailed finite element analysis was carried out, again using SAFE to assess movements, etc., and a subsequent quantitative risk analysis was undertaken and presented to the TWDC, who decided that the mains should be lined prior to excavation works. A significant amount of demolition was needed before the diaphragm walls were constructed, and consideration had to be given to the amount of substructure retained to form level plateaus for contractors' plant, etc.

Retaining wall D

This wall, approximately 250m long, is constructed from contiguous bored piles of varying diameter and height to accommodate the change in levels between the lower riverside plateau and City Road. Wall D varies in height from 4m to 15m and provides lateral support to both the internal and external highways. The piles are capped by a cast in situ reinforced concrete wall and both the piles and the wall are restrained by permanent ground anchorages up to 35m long (Fig.16). This wall will be situated immediately to the rear of future buildings planned for this area of the site (Fig.17). Solutions have been devised with the developer on how to incorporate the inspection and monitoring access areas for the anchorages behind the buildings.

Retaining walls G, H, and J

These walls towards the eastern end of the site are existing brick-vaulted mass concrete structures which are to be refurbished/rebuilt during 1996 to suit the development of housing in this area of the site.

Multi-storey car parks

These have been designed to blend into the hillside as unobtrusively as possible. In their role as project managers and designers of this part of the site infrastructure, Arups appointed the Newcastle-based architectural practice, the Napper Partnership, as subconsultant architects for the car parks after a selection process by a TWDC panel (Figs.18-20). The car parks are split-level, multi-storey, reinforced concrete, clear span structures. In the first car park four levels of parking (eight half levels) provide 500 spaces over an area some 34m wide by 100m long. Although built into a hillside it is effectively free-standing, the required highway support being provided by Retaining Wall B. The second car park has six levels of parking providing 656 spaces over an area of the same width but 30m longer than the first. This car park is fundamentally different from the first, however, in that it is to be constructed into the hillside and will provide support to the highway. The cladding to both structures is predominantly brick, with stone-coloured precast concrete units. Each car park has as its main feature a glazed main staircase and lift core, the staircase landings being pre-

16.
Retaining wall D -
installation of ground anchors,
January 1994.

17.
Completed retaining wall D,
June 1995.

manufactured panels of translucent glass blocks cast into concrete surrounds. The panels are supported by in situ reinforced concrete beams spanning across the landing areas onto the perimeter reinforced concrete shear walls. The lifts are located behind external curtain walling which is in turn supported by a structural steelwork framework.

Much thought has been given to security, general safety of users, and operation of the car parks. As a result the first building, completed in August 1995, has received a Gold Star award from the Northumbria Police Department. Construction of the second car park commenced in November 1995.

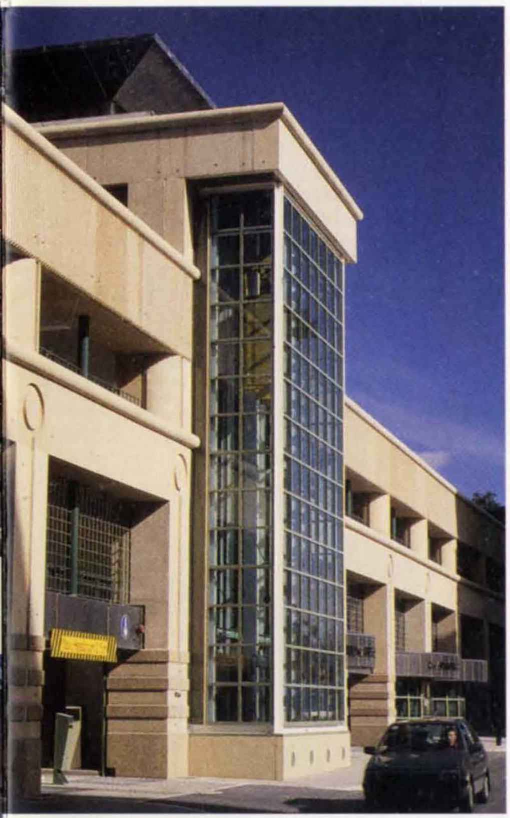
Hard landscape, roads and services

Considerable thought has also been given to the hard landscaping on and about the site. The prime emphasis has been on quality, with a determination to ensure that the materials traditionally used on the quayside - as in the sandstone paving and granite kerbs - are incorporated into the development.

Attracting the general public to the development has also been a major objective, with significant expenditure on landscaped entrances, sculpture, stone, and metal craftwork to enliven public spaces (Fig.21). New roads and service routes have been designed to adoptable standards throughout the site and these facilities will be maintained and operated by the management company set up to run the development.

Conclusion

Designing the civil engineering infrastructure for this prestigious development was a fascinating challenge and much effort has been made to ensure that it blends into this historic area of Newcastle upon Tyne. The design of the retaining walls in particular has taxed the ingenuity of Arups' engineers, but in the ways whereby the problems of level have been solved, the TWDC have a flagship development (Fig.22) which they anticipate will be a benchmark for years to come.



18. Above: Front elevation
of multi-storey car park Phase 1, September 1995.

21. Entrance at Sandgate Steps, September 1995.

19. Interior of Phase 1 car park.

20. Below: Roof deck and
pergola at car park Phase 1.

22. Quayside development at September 1995.

Credits

Client:
Tyne & Wear Development Corporation

Developer of Phases 1 and 2: NQD plc

Principal consultant and designer for the civil engineering infrastructure:
Ove Arup and Partners Yasmeen Al-Boutie, Simon Averill, Ian Bambrick, David W Brown, Mike Brown, Martin Butterworth, Julian Cheung, Robin Comrie, Dominic Cropper, John Daley, Colin Dodds, Allan Driscoll, Mike Francescon, Graham Gedge, Andrew Goodfellow, John Gregory, Nigel Harrison, David Hillcox, Stuart Hood, Jenny Lines, Paul Littlefair, Neville Long, Trisha Love, Stephen Lumb, Stephen Mason, Ray McIver, Phillippa O'Neill, Colin Peart, David Peck, Alan Rowe, John Sanford, Ian Scott, Malcolm Shaw, Steve Shaw, Tony Sheehan, Brian Simpson, Angus Stephen, Stuart Stephen, David Stevens, Angela Warneford, David Williams, Andy Woodland.
Martin Bayly, Graham Bell, Andy Christie, Cliff Jessett, Robert Leslie-Carter, Garry Miller, Philip Tarren, Bob Tyson (site team)

Masterplan architect:
Farrell and Partners

Sub-consultant and architect of the car parks:
The Napper Partnership

Sub-consultant and landscape architect:
Branson McGuckin Associates

Sub-consultant quantity surveyor:
Gardiner & Theobald

Contractors:
Costain Civil Engineering Ltd:
(Quaywall repairs Phase 1)
Sir Robert McAlpine: (Retaining wall A)
Edmund Nuttall Ltd: (Retaining walls B, D and K)
Lumsden & Carroll: (Sandgate Steps
and Phase 1 roads and services)
Harbour & General: (Quaywall repairs Phase 2)
John Laing Construction Ltd: (Car park Phase 1)
Mowlem Northern Civil Engineering:
(Phase 1 hard landscaping)
AMEC Building Ltd: (Car park Phase 2)
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Michael Baker: Tyne and Wear
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Eric Carter: The Napper Partnership
Peter McGuckin: Branson McGuckin Associates
Illustrations:
2: Airfotos. 1, 6, 9, 11: Sean McDermott/Jennifer Gunn. 3: Tyne & Wear Development Corporation
4, 5, 7,10, 13-22: Ian Bambrick.
12: Mike Blenkinsop

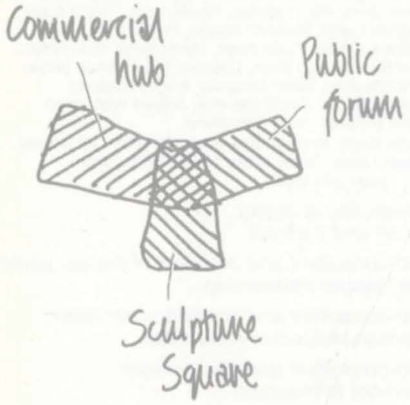
Sandton Library, Johannesburg

Craig Thompson

1. West elevation, viewed from Sandton Square.

Introduction

This development for the Town Council of Sandton on the outskirts of Johannesburg comprises not only a new central public library but also Council Chambers within the same main building, and a low-rise art gallery to the south, embracing a sculpture court. The gallery has two wings modulated internally by a hierarchy of brick arches and buttresses which create toplit pockets of space for exhibits. To the west and east are important public squares, one of them a new commercial space with shops and offices and the other a public forum, between which the library building has been designed to form a link. This site is an awkward, wedge-shaped tract, squeezed at odd angles between the squares (Fig. 2).



2. Site constraints.

The architects, GAPP Architects, decided at the outset that the site should dictate the architecture and they therefore allowed its awkwardness and difficulties to develop a unique character for the building. Budget constraints on the building, coupled with some opposition within the Council to development, forced an accelerated construction programme. In addition, only preliminary architectural information was available at the start of the works, final documentation evolving in parallel with the construction process. The tight budget also dictated the 'look' of the building; structural costs for both library and art gallery were only some £2.4M/SAR14M, of which the former accounted for about 70%.

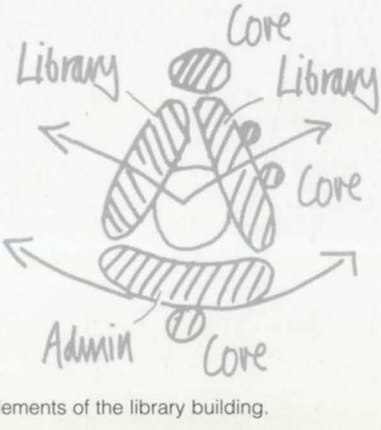
Architecture

As well as a stock of some 85 000 volumes, the library has audio-visual and CD-ROM facilities, and a computerised network system. It has a triangular plan shape with three wings organised around a similarly triangular atrium, partly glazed over to create a bright, light-filled space. Access from one square to the other runs both through the building itself and along an external walkway by its southern side. On plan the layout is simple: the east and west wings contain library shelving while the slightly curving south segment houses support facilities (Fig. 3). In section, however, it is more complex, as a one-storey difference in level between the external squares had to be resolved. This was done by an ingenious helical floor arrangement, consisting of six half-levels. The internal atrium thus became the focus of the building's circulation via a suspended spiral pedestrian and trolley ramp. At the northern tip of the building there is also a cylindrical core containing lifts. The topmost floor is a conventional level floor housing the executive of the local council, as well as a semi-circular debating chamber. The east/west orientation of the site, coupled with the need for large areas of glazing on the library floors, gives rise to deep set-backs in the façade. The external façades are of brick, complemented by elegant structural steel balustrading and balconies with open grid flooring. Apart from the deep reveals, climatic regulation takes the form of retractable fabric sunscreens which are automatically controlled by a solar cell linked to the sun angle.

Construction

Work commenced with bulk earthworks in January 1992, and full practical completion was reached in February 1994. As there was little money for finishes, the structural frame was expressed. No ceilings were provided and floors were generally finished with carpets, apart from the atrium which has a Canadian maple timber floor. As a result the frame is of expressed off-shutter in situ reinforced concrete, which set high demands on detail and finish quality. The resulting finish is of a comparable quality to the in situ stitched precast frames more conventionally used in this type of expressed structure. The high quality finish can be attributed to the careful attention to detail on the part of structural engineer, architect, and main contractor. Columns are at 8.4m centres, and the suspended slabs comprise 425mm thick coffered slab construction with power-floated top surfaces and expressed soffits. Electrical and data services reticulation is via cast-in conduits within the 100mm structural topping. The stepped helical slab arrangement is braced by concrete cores at the south and north end of the building. Extensive openings within these core areas provide vertical services reticulation.

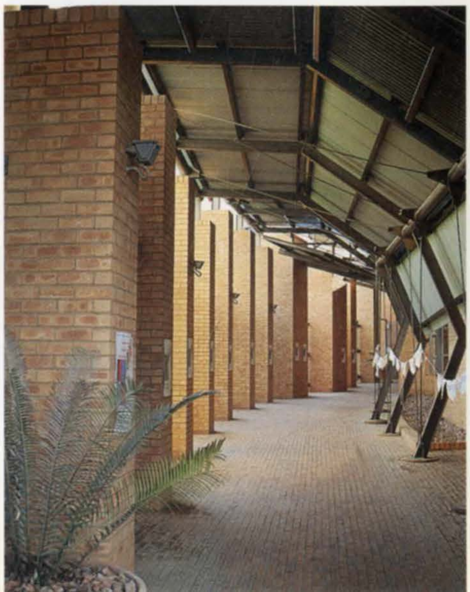
Part of Arups' appointment as structural, civil, and geotechnical consultants was to advise on all aspects of the external brickwork. The building is clad in archaic honey brick masonry walls, and the mortar pigmented to resemble the colour of the brick and pointed flush with the face to give a planar appearance. The brickwork has deep piers and soffit reveals requiring in situ concrete lintels. The architectural requirements for consistent joint widths and planar appearance meant that careful consideration had to be given to the masonry's physical properties and long-term performance to assess suitable expansion joint positions and brickwork support details. On the east-facing façade twin cylindrical towers comprising full-height, self-supporting brickwork 'chimneys' contain external stair and lift cores.



3. Elements of the library building.

4. East elevation entrance from the forum, showing cylindrical stair and lift cores.

5. Covered walkway on south side of building.



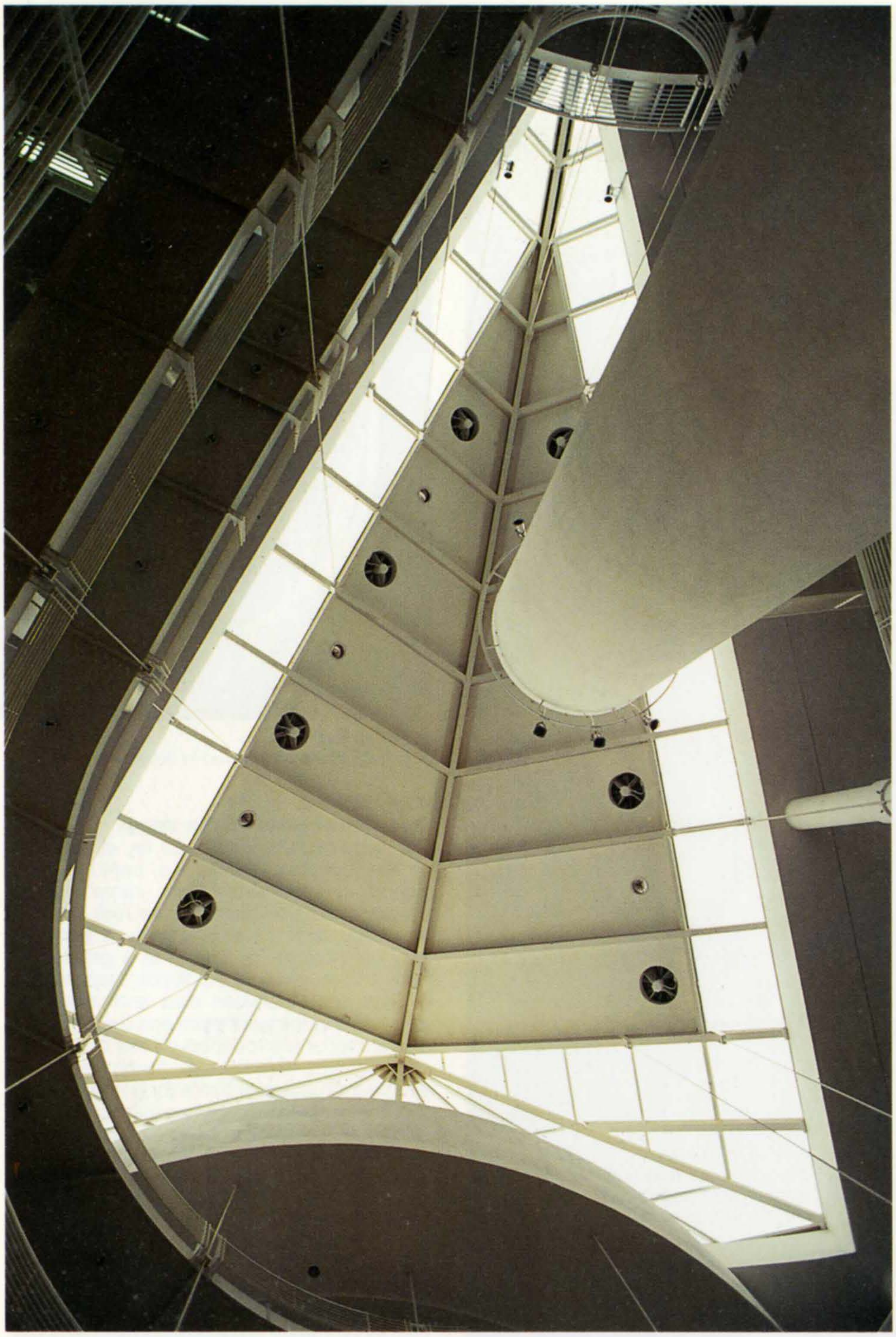
6. Atrium reading pit, showing Canadian maple floor, and suspended pedestrian ramp.

8. Pedestrian ramp, also showing lift core down to floor level.

Atrium roof and spiral pedestrian ramp

The key structural challenge lay at the heart of the building. Within the central atrium space a structural steel ramp spirals upwards, suspended from the roof - also of structural steel - by steel rods. It works its way up through the atrium at a gradient of 1:12 and touches all the floors, stepped half a level apart between east and west. The ergonomics, the aesthetics and the character of the interior are founded on this one particular element. GAPP gave Arups license to evolve a structural scheme for both ramp and roof that would be visually exciting. The tight budgetary constraints inevitably had a strong influence on the final scheme, and the roof and ramp geometry evolved from an interaction between economy and invention. The steel atrium roof has visually expressed universal beam portal frames, in two section sizes only so as to maintain aesthetic proportions. Because of the necessity for the hangers to the ramp to interact orthogonally with it, the atrium portal frames are kinked in plan. Any tendency to 'roll over' is resisted by providing a central spine tie element.

7. Lift core at atrium roof level encircled by pedestrian ramp.



9. Above: Atrium roof.

The roof is partly glazed and partly sheeted, with ceilings below the sheeted areas. The hangers are the type of high yield, threaded steel bars usually used in coupled reinforced concrete applications. This was both aesthetically and practically desirable as the necessary splicing and anchoring components could be relatively cheaply and easily sourced. The ramp cross section comprises rolled flat bars forming stringers, and a stiffened steel soffit plate as the underside. The soffit plate acts as a permanent shutter for a small amount of structural concrete to form the surface onto which finishes were applied. This concrete was also required in order to provide the necessary mass to tune the inherently 'live' structure to a natural frequency which would be acceptable from a vibration point of view. The whole ramp structure was successfully modelled using OASYS GSA software.

All connections were fabricated from welded and bolted assemblies of platework as budget constraints did not permit castings to be used. The integration of architectural and engineering design in the atrium roof and spiral ramp created an exciting end product, recognized by the South African Institute of Steel Construction as both overall winner and winner of the architectural/structural application category in their 1995 Awards.

Conclusion

The resulting library areas are bright and intimate, and welcome the prospective user with interesting arrays of shelves and quiet workspaces. The main contractor Abcon won their second successive South African Interbou Quality Award in 1995 with this building. Pedro Roos, the project leader of GAPP Architects, summed it up well when he wrote: 'As the users of the building take over, the design process continues. It is their inhabitation of the building that refines the character of the building as it becomes the backdrop and stage to this colourful and diverse South African community.'

Credits

Client:
Sandton Town Council

Architect:
GAPP Architects and Urban Designers
In collaboration with
Floris Smith and Meyer Pienaar cc

Structural, civil and geotechnical engineers:
Ove Arup Incorporated John Abbott, Willie Barends, Bruce Bulley, John Gibbs, Rob Lamb, Nicholas Mdluli, Jayanti Odhav, Roland Orlopp, Ash Parshotam, Errol Shak, June Smith, Kevin Swan, Craig Thompson, Hannes Vermeulen, Peter Chiesa

Quantity surveyors:
Walker Maré

Main contractor:
Abcon (Pty) Ltd

Mechanical engineers:
Richard Pearce and Partners Inc.

Electrical and fire engineers:
Everitt and Germishuisen cc

Landscape architects:
Environmental Design partnership (Pty) Ltd

Interior designers:
Frame

Lighting consultants:
Paul Pamboukian

Plumbing consultants:
Elaisov and Franklin

Illustrations:
2, 3: GAPP Architects/Nigel Whale
1, 4, 6, 7: Gavin Byrne
5, 8, 10: Craig Thompson
9: GAPP Architects

10.
Pedestrian link between
ramp and administration area
on the south side of the building.

1. Inland Revenue HQ looking north; Nottingham Castle is at the top of the picture.

The New Inland Revenue Centre, Nottingham

John Berry James Bown John Thornton John Turzynski Martin Walton

The competition

When the Inland Revenue (IR) decided in 1989 to relocate much of its work from London, the site chosen was the Castle Meadow area in Nottingham. Next to the Nottingham Canal and dominated by the Castle on its rock, it is close to Nottingham Station and adjacent to Wilford Road, a main thoroughfare from the south.

The site, though run-down, is well served by transport and close to the city centre, and thus was ideal for an office development.

The piled foundations for a design-and-build scheme were already in place when in March 1991 work was suspended, following criticism from the Royal Fine Art Commission, English Heritage, and the Nottingham Civic Society amongst others.

With the agreement of Treasury Ministers the IR decided to choose a new design through a staged architectural competition, which was won by Michael Hopkins & Partners with Ove Arup & Partners as engineers.

The competition brief called for value for money in terms of capital expenditure, quality, and running costs. It also required a design which not only suited the IR's current operations but would be flexible enough to adapt to changing needs, including the possibility of another occupier. There was a strong preference for a 'green' design with maximum use of natural light and ventilation. Other important criteria were the short construction programme and £50M construction budget. The design also had to maintain views of the Castle from the south.

The winning scheme

Early decisions were that the Centre should be a collection of individual buildings along a central tree-lined boulevard and that these should be of brick, in sympathy with existing buildings in the area. The wish to use natural ventilation led to a building width of 13.6m, and heights limited to three and four storeys to preserve the Castle views. There are four L-shaped and two courtyard office buildings, and an amenity building entirely different in design. The office buildings are built from repetitions of the same elements - straight lengths of office space with stairs and cores in the corners, and stairs at the ends of the L-shaped blocks. There were two important influences on the design: Glyndebourne Opera House[1], already under construction, and the New Parliamentary Building (NPB) at Westminster where the basic principles of the design had already been established.

The latter is a courtyard building which essentially comprises three basic components: load-bearing stone piers, precast concrete floors and infill façade panels. The same logic is followed at Nottingham, with the difference that the piers are of brick. The use of these has an immediate resonance with Glyndebourne, but other features in common are the rounded ends of the L-shaped blocks and a change in construction at the top floor, which jetties out and becomes lighter. The buildings also share a similar roof construction, lead-covered ply panels. From the beginning the desire for a 'green' building was of paramount importance. Here too there were close links with the NPB: the façade design minimised solar gain while the building fabric was used to absorb heat during the day. The environmental concept is simple. Air enters either through full-height sliding windows or through low-level, fan-assisted ventilation grilles, and is extracted through the cylindrical stair towers acting as solar-assisted chimneys. By drawing air through the building at night the fabric can be cooled to help provide comfort the next day. The deep reveals of the brick piers and the louvred balustrades provide shade, while a light shelf gives the occupants additional shade and reflects light onto the ceiling. There are blinds in the triple-glazed windows.

The driving force behind the design is the complete integration of architecture, structure, and environmental concepts. There are no applied finishes and many components perform several functions. This economy of design is not only an important factor in the building's appearance but also helped meet the cost and programme requirements. The high net-to-gross ratio of 89% clearly shows the benefit of this approach. Cost, programme, and the nature of the client also influenced the design team's competition strategy. Though confident that its proposals could be proved during detailed design, the team also developed fall-back solutions so that those aspects of the design which were novel or raised doubts could be modified or supplemented if necessary without compromising the overall solution. In this way it was shown that although the design was technically innovative the risks were low.

Structure of the office buildings

The structure differs slightly from that proposed in the competition design. At that time the floors were to be a conventional system of precast concrete slabs supported on precast beams at 3.2m centres, spanning from in situ brick piers onto in situ reinforced concrete beams and columns in the centre. The in situ beams made it simple to connect the precast beams while allowing the column spacing to be opened out to 6.4m. During design development it became clear that the central columns would interfere with space planning, while the depth of beam needed to span the full width would be visually heavy. The solution was to adopt the design already developed for the NPB, a wave-form folded plate floor which spanned from wall to wall without intermediate support. During the competition the project managers had concluded that the solid brick piers could be constructed within the time available.

Nevertheless this was clearly a critical activity, as the work could be badly affected by the weather and there was the cost of scaffolding. Arups therefore proposed that they be prefabricated off-site.

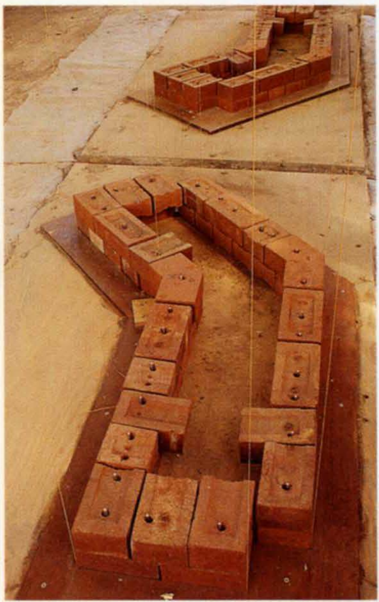
The piers were built around a single steel bar anchored into a stainless steel plate at the base of the pier, the bar being used as a lifting device until final placing, at which time it was removed. The piers were made by Trent Concrete, a local firm also responsible for the floor units, who had both the necessary expertise to produce drawings and schedule production, and workshop and storage space with sufficient lifting capacity.

The piers were built in ideal conditions - warm, dry and well-lit - and templates and lines enabled the bricklayers to achieve a high standard of quality and accuracy. Precast saddle-shaped padstones were added to the tops of the piers before storage.

Construction on site was simple and fast. The piers were placed on pre-levelled packs and plumbed with adjustable props. The floor units were placed on packs on top of the piers, immediately becoming a stable platform. All that remained was to grout the joints and stitch the slabs together.

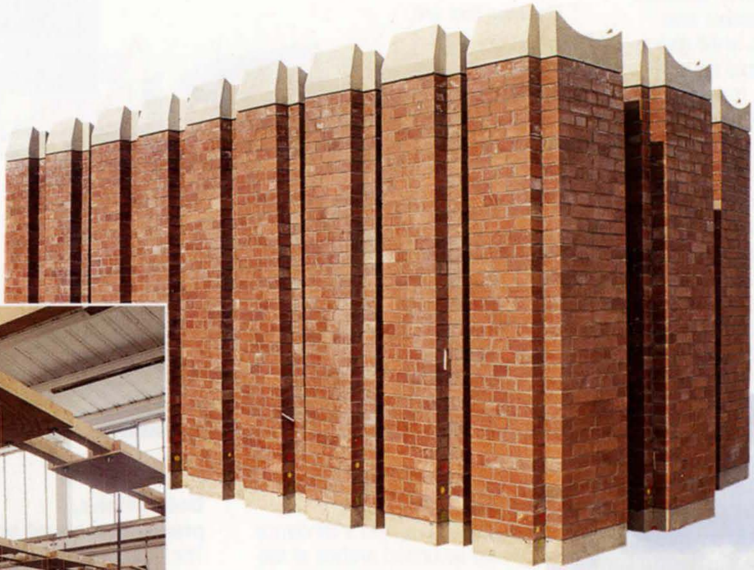
The remainder of the structure is conventional. The foundations are piled, with lateral stability from reinforced concrete cores in each corner. Also in the corners of the buildings are circular steel and glass stair towers covered by PTFE-coated, glass fibre membrane umbrella roofs, motorised to allow them to be raised and lowered.

The lead and ply roofing of the offices is supported on exposed steel trusses formed principally of double angles and tie bars, a development of the design used over the Rehearsal Stage at Glyndebourne.



3.
Base for preformed brick pier.

4.
Brick piers under construction.



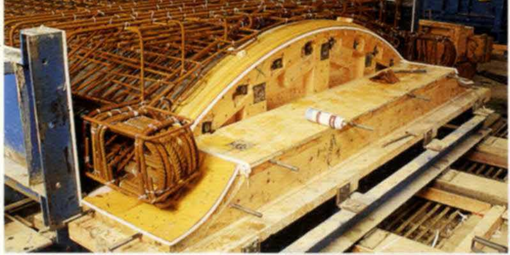
5.
'Terracotta army' awaiting installation.

6.
Lifting a brick pier.

7.
Brick piers ready for floor units.

2. Left:
General view: glass stair tower with lifting roof on the right of picture.

Precast floors



8.
Timber mould
for ends of units.

9.
Steel moulds
for floor units.

10.
Lifting a floor unit.

11.
Placing a floor unit.

Description

The floors were precast in 13.6 x 3.2m units. Each weighs about 26 tonnes, has a vaulted form, and sits on brick piers at its four corners. The joint between units at the centre of the pier thus forms the trough of a wave. A major benefit of this change in design from the original precast slab concept was the reduction in the number of components to be made, transported, and erected - which led to time and cost savings. The folded plate floor is very efficient: not only is it light in structural weight, it also provides a zone for fans, radiators and services crossovers while giving the maximum possible floor to ceiling height. Also, the rhythm of the wave form helps give definition to both cellular and open plan offices below.

The units are 800mm deep with a 550mm change in soffit level between high and low points of the wave. The minimum thickness is 130mm but the inclusion of steps for the raised floor pedestals and thickenings for in situ stitches led to an average thickness of 225mm. There are openings for light fittings, fire detectors and PA equipment.

Stitching them together created a floor diaphragm to transfer lateral loads to the in situ cores and provided resistance to asymmetric loads across their width. Because lateral stability was provided by the cores rather than frame action, unlike NPB, it was possible to divide the floor along the centres of the piers. The consequent four-point support avoided the need for temporary propping during construction. The ends of the units appear in the façade where the joints were grouted and pointed to close potential water paths into the building.

Analysis

The analysis reflected the condition during erection when isolated units span between piers under their own weight. The subsequent loads of raised floors, floor services, demountable partitions and live loads are resisted by the units in combination. The scheme design calculations were verified using GSA shear beam 3D grillages to represent each unit. Under superimposed dead load and live load the in situ joints were modelled with bending elements and the results merged with the dead load analysis to give the design envelopes.
The analytical models included up to five units with various boundary conditions to represent different building arrangements.

Tie rods

The precast units had a tendency to spread as untied arches at the points of support. Restraint was necessary to allow them to be handled, stored and erected. After the floor had been stitched together it was only necessary to stop the spreading at the end supports but this was difficult to achieve. Early schemes to restrain the spread used reinforcement or flexural steel elements across the tops of the units. However, this was expensive and could not easily be worked into the façade or contained within the raised floor.

The final scheme has external steel ties which are visible in the façade. The tie bars were sized to restrict their extension under load. The extension under self weight was absorbed in the 20mm joint between units before grouting at the piers. Subsequent extensions result in a general spreading along the façade. The cores provide only a small amount of restraint so the buildings are designed to accept this expansion.

The first idea was to cast the tie rods into the concrete but Trent, who made the units, proposed a threaded end detail so that they could be installed after casting. This simplified the formwork.

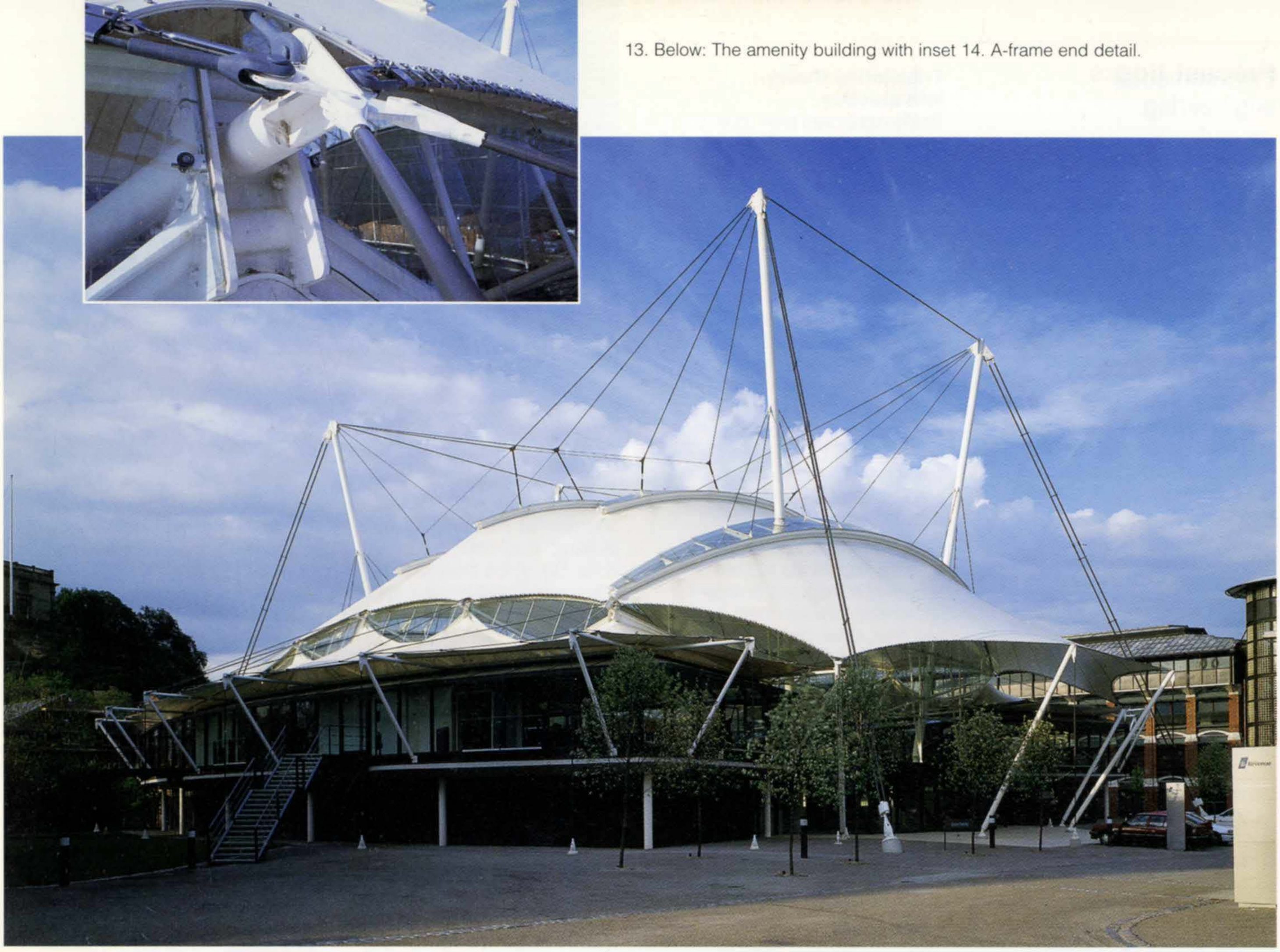
Deflections, precambers and presets

The GSA models were calibrated with ADSEC analyses so that full time/history predictions of deflections could be made. It was desirable for the 13.6m span units to have a permanent curvature to the lower edges of the concrete to avoid a drooping appearance.
The target was 10-15mm of camber under a nominal live load of 1.0kN/m^2 two years after construction. To achieve this the units were cast with an initial 50mm precamber; shadow gaps at the joints between units mask any level differential. At the cores the typical units are alongside shorter units spanning onto core walls, the shorter units preset to minimise level differences before stitching.

12.
Side elevation detail.

Curing, storage and lifting

The units were cast in enclosed conditions, left in the forms for two days and kept in the same conditions for two more days before being placed in storage. They were supported at the permanent bearing positions at all times after de-moulding, as support from other positions would have left marks, visible in the finished building. Moreover, the tie rods were positioned to control spreading of the units when supported at these points. Support at other locations was liable to induce cracking at the crown of the units. For the same reason the units were lifted from points close to the permanent supports. This had the additional benefit of placing the unit on the pier in its deflected shape and limiting the rotations imposed on the pier to those from creep and imposed load deflection. Storing all the units in the same way gave consistency of creep deflection. The accuracy of manufacture and assembly was carefully surveyed to compare predicted and actual deflections.



13. Below: The amenity building with inset 14. A-frame end detail.

The amenity building

This contains the staff restaurant, sports facilities, and a crêche. It takes the form of two gently curved double-storey blocks flanking the central sports area, the ends of which are closed at one end by the reception area and at the other by the staff nursery.

Both are fully glazed. The roof is a PTFE-coated, glass fibre membrane. In size, plan form, and construction type, the building is similar to Hopkins' earlier Schlumberger building[2]. There, the membrane roof covered only the central space - thus making a clear distinction between this and the side blocks - whereas at the IR it extends over the whole building in order to unite it. Another important difference is that at Schlumberger the membrane is clamped down to the side block roofs, which makes it appear more solid.

At Nottingham the design team wanted the edge of the membrane to be visible, as with the Mound Stand at Lord's cricket ground[3], so that its thinness could be apparent and the roof seem lighter.

Covering the whole building with a single membrane presented two architectural problems : how to generate a form which was not dull and uniform and how to reveal the building's organisation. The engineering problem, as with any membrane structure, was to develop a form with sufficient curvature.

The solution to all three problems was to separate the membrane over the sports hall from those over the side blocks. The discontinuity not only emphasises the difference in function, it also breaks up the bulk of the roof and, most importantly, allows another fabric edge to appear.

The early designs used ring details of the same type as the Mound Stand to pick up the main roof. By changing these to glazed ladder trusses more light was introduced, and by contrasting the angularity of the ladders with the curves of fabric the roof's appearance was improved. Introducing ladders at the point where the masts passed through the roof not only avoided the physical and visual weakness that would have occurred if the masts had passed through the fabric, it also provided a way of joining the glazed end walls to the roof and allowed the ends of the roof to continue on as pure canopies.

The form of the main roof is generated by six elliptical ladder trusses suspended by steel bars from four masts. The edges of the roof are pushed out by raking struts at the canopy ends and by raking A-frames at the edges over the side blocks. The points of the A-frames are attached to the ladders by cables, and from them are suspended the insulated ceilings of the side blocks; between them span glazed lenses, forming the upper boundaries of the side block roofs. The outer edges of the latter are held in position by props and raking struts from within, and tied down to piled foundations.

The design of membrane and tension structures is complex, but this roof was particularly so because of the interaction between the two structures, the main roof over the sports hall and the two side block roofs. Changes in load on the roof cause strain in the suspension rods. The geometry of the system is such that these strains would result in unacceptably large vertical movements at the tips of the A-frames without further measures. To reduce these deflections, prestressed ties below the ladders connect to the inner props of the side block roofs. Changes in load on the roof are then carried by changes in the prestress in this lower tie system, the geometry of which allows little geometrical magnification of the strains. The lower system is thus stiffer than the suspension system and provides good control over deflections.

The loads applied to the points of the A-frames are transmitted down their legs to ceiling level, where strut/tie tubes carry them out to the edge of the building. From there they are taken to ground via a raking strut and tie system. Unbalanced loads on the fabric result in unbalanced loads on the A-frames and lower roof system.

These are carried by a continuous perimeter tie system at ceiling level which is anchored down to the first floor at each end of the side blocks.

One of the difficulties with such structures is to be sure that all likely load patterns and combinations have been considered and that there is an adequate structural system to carry them. Another concern is the design of the details. The loads, geometry and fabric detailing requirements are so prescriptive that if the problem is other than straightforward there is a risk of producing a design which works but looks clumsy. It is a weakness in the design of many membrane structures.

The details at the ends of the A-frames where upper and lower membranes, glazed lenses and cables come together were particularly difficult. The forces were substantial, the geometry complicated, and the membrane attachment imposed its own requirements. The situation was even more complicated where the glazed end wall and associated ladder truss were part of the assembly, and it was particularly gratifying that after a great deal of work these details appear as clear and elegant as the simpler details.

The first floor structures and the bridges which link them are in situ reinforced concrete coffered slabs.

Continued on page 17 ▶

Environmental engineering

'Natural ventilation'

People prefer to open windows and have contact with the outside world - but still feel comfortable. These preferences are reflected and reinforced in many user studies. 'Natural ventilation' has become a figure of speech which encapsulates this objective but rarely means what it says. Simply opening windows is not in itself a solution. Other factors need consideration, such as solar shading to minimise heat build-up, thermally heavy construction to dampen temperature fluctuations, exposed surface area for heat transfer, adequate volume for ventilation flow, tall rooms for stratification and a means of controlling air flow during the day and, more importantly, at night for pre-cooling the exposed structure (capacitive effect).

The engineering design skill lies in integrating these principles into a coherent architectural form.

Influencing factors

Four basic ideas drove the environmental design: high performance façade, solar-assisted ventilation, thermal mass, and good daylight levels. Energy was to some degree a secondary issue on the assumption that a low energy design would flow naturally from a sound environmental strategy, which it did. Excessive solar gain is limited by the façade so that only a small fraction is actually admitted as heat.
Windows are triple glazed with a low emissivity coating and a blind in the outer cavity. The brick piers, balcony and light shelf, which also reflects daylight onto the ceiling, shade the window. Conceptually the window can be thought of as two distinct components. The lower portion is concerned with view and ventilation while the upper part channels daylight into the room. Cool outside air is drawn through the building by the combination of internal heat gain and solar-assisted towers. Temperature fluctuations are damped by the exposed concrete ceiling.

Translating theory into practice

This is easier said than done. It needs a thorough understanding of the variables and their complex interaction. To aid the design a computer model was developed to analyse air flow patterns, thermal performance and comfort. This was supported by a 1:50 saline fluid model study at the University of Cambridge. The saline model is buoyancy-dependent and takes no account of the damping effects of thermal inertia. However, when corrected for these effects, a good correlation with the computer model was obtained. Experience with saline modelling on Glyndebourne and Cable and Wireless[4] gave confidence in the results.

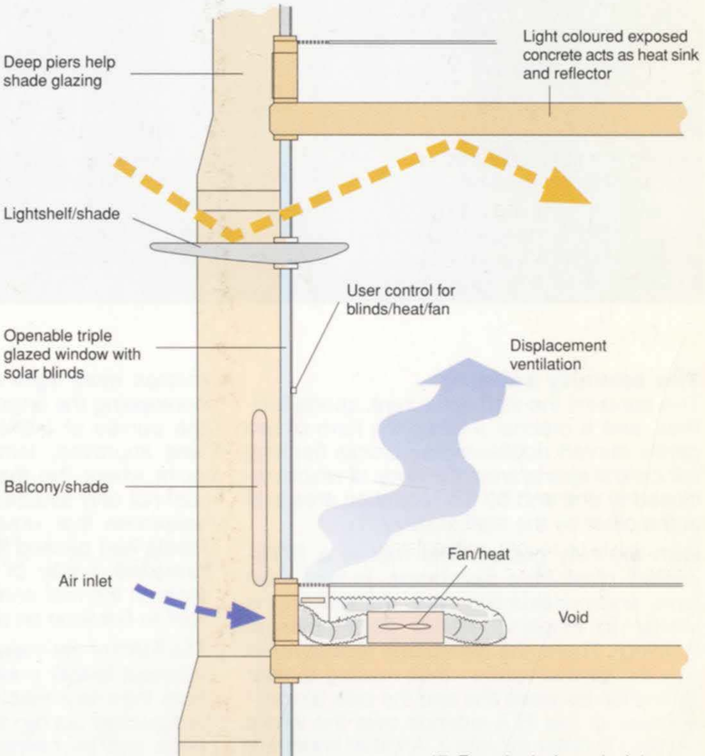
From the model studies it was possible to generate a series of sensitivity nomograms to show the relationship between tower height and area, tower inlet area, corridor width, internal height, orientation, glazing area, window opening, internal heat gain, internal temperature and air flow rate.

It was then possible to decide on the following:

- Tower height:
  7m above the last level served
- Tower diameters:
  5m main tower,
  3.6m secondary tower
- Room height: 3.2m
- Structure height: 2.6m
- Entry to tower: 4.0m^2

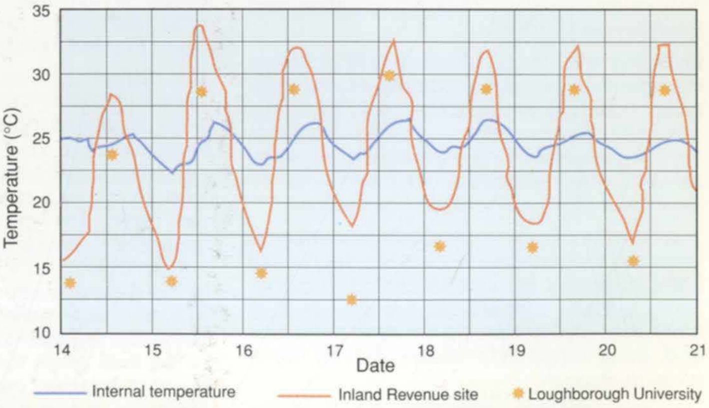
Interestingly, the tower entry proved to be the limiting orifice in the system and therefore the most critical for air flow. Both models allowed the contribution of the solar-assisted tower to be assessed by turning it on or off. The air flow increased from 4.8 to 6.2 air changes/hour with the tower operating in solar mode: an important contribution. Because the tower needs height above the inlet opening to work effectively, the top floor differs in design from the lower floors. It relies on volume, not mass, and is ventilated through roof ridge vents, not the tower. In fact the tower is closed to the upper level to avoid warm air flowing from the tower itself into the top floor office. Magnetic catches hold open the lower doors to the tower to ensure adequate air flow through the building. They close in the event of a fire. During the theoretical and saline modelling it became apparent that opening a window close to the tower caused short-circuiting of the air supply. This coincided with other concerns at that time such as noise from the railway and how to open the windows at night to pre-cool for the next day's comfort. The dilemma was resolved by installing a small fan under each window drawing fresh air directly from outside. Windows can still be opened at will.

16. Office interior

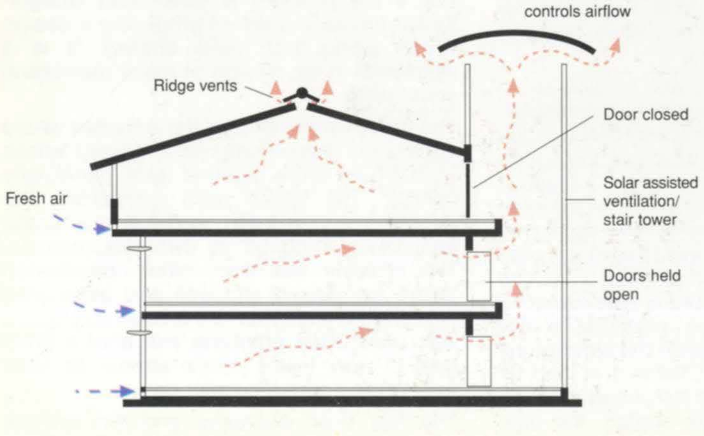


17. Façade design principles

18. Below: Internal and external temperatures during one week of the August 1995 heatwave. Readings from the Meteorological Office-approved station at Loughborough, some 30km away, are included for comparison and corroboration.



15. Ventilation design principles



Special algorithms have been written into the Building Management System (BMS) software to control the pre-cooling cycle. Fabric-covered tops to the towers rise and fall in response to the internal environment. Generally they open on hot days and nights and close in winter. Their operation is governed by the BMS computer and sensors operating in conjunction with the input fans and roof ridge vents.

Comfort in non air-conditioned buildings is a matter for much debate but Fanger[5] is still the most practicable way of coming to a meaningful conclusion. An air temperature of 27°C was taken as the upper limit for 80% of the occupants to be satisfied. This takes account of the radiant field from the cool concrete ceiling and the slightly warm window (<30°C). A study of past weather data coupled with our thermal model indicates that 27°C is likely to be exceeded only 22 hours per year.

The occupants have been given as much control over their environment as possible. Blind tilt, heating temperature and fan speed are controlled from a panel mounted on the window frame of each bay. Lighting is adjusted and dimmed from an infra red, hand-held controller, and the edge uplighting zone is solar-compensated. The sliding glass doors can be opened in stages from top tilt to fully open.

Monitoring

The objective has been to provide an environmentally responsive building which responds to individual preferences, although the BMS will intervene from time to time to ensure stability. The building was monitored for three weeks of what turned out to be one of the hottest UK Augusts on record, with outside temperatures peaking at c.30°C for six consecutive days in one week - a severe test of any design.

Did it work? Internal temperatures on the lower floors ranged from 22.5-26.5°C while the top floors, which do not have the concrete ceiling, were a few degrees warmer. During the monitoring period the occupants were asked to record information about blinds, lighting, fans, and windows.

Prior to this Arups gave some workshops to IR staff on the thinking behind the design.

Initial results are encouraging insofar as internal temperatures on the lower floors were 4°C cooler than outside, and a user survey indicated a reasonable understanding of how the building works.

For instance on the hottest days, when it was cooler inside than out, most of the windows were kept closed and the fans off. BRE and BSRIA are continuing to monitor the performance under the Building Good Practice and Night Cooling programmes.

Continued from page 15
▼

The membrane effectively provides no insulation so the sports hall is considered as an unheated space. Temperatures are predicted to track outside conditions within a few degrees. Opening vents in the glazed end walls provide cross-ventilation on hot days, while electric radiant heaters on the side blocks raise the temperature in the playing area to 13°C in cold periods.

One of the benefits of a membrane roof is its translucency, in this case 12%. Not only does this give a very nice quality of light, it also means that the use of electric lighting is greatly reduced. The membrane admitted sufficient diffuse radiation for the heating and lighting to be reduced by so much that the energy used was less than that of a conventional building. The combination of glass and membrane was very successful.

Conclusion

Construction started in January 1993 and was completed in March 1996. The design of the buildings, and their use of the Nottingham district heating scheme - a heat and power system which uses refuse as fuel almost entirely - meant that this was the first project to receive maximum points under the BREEAM (Building Research Establishment Environmental Assessment Method) scheme. Burning waste produces no more CO_2 than if it were allowed to rot as landfill, so heating the IR buildings effectively creates no CO_2 emissions. Structurally, the IR HQ was honoured in October 1995 by an international award for fabric architecture to the amenity building from the Arbeitskreis textile Architektur, Frankfurt.

As for the environmental controls, the encouraging initial results from the monitoring during the record temperatures of August 1995 show that high thermal mass coupled with night cooling in an efficiently designed building is effective.

The outcome of the current monitoring should enhance knowledge of how such designs function in practice.

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Credits

Client:
The Inland Revenue

Architect:
Michael Hopkins and Partners

Consulting engineers:
Ove Arup and Partners Carl Bauer, James Bown, Steve Cliff, Ian Gardner, Ray Ingles, Yuko Mabuchi, Giles Perry, Caroline Ray, Paul Summers, John Thornton, John Turzynski, David Wilde, Aaron Wong, Shirin Yoosoofsah (Structural)
John Berry, Judy Coleman, Trevor Levesley, Paul Sloman, Martin Walton (Mechanical)
Graham Beardwell, Bob Kelly, Geoff Shotter (Electrical)
Mike Ebsworth, Terry Watson (Public health)
Chris Murgatroyd (AR&D)
Bob Venning (Lighting)
Brian Coles, Robin Lee (Arup Geotechnics)
Fred Brenchley (Arup Acoustics)
Chris Barber, Andrew Gardiner, John Hopkinson (Arup Fire).

Project managers:
Turner and Townsend Project Management

Quantity surveyor:
Turner and Townsend Quantity Surveyors

Management contractor:
Laing Management

Illustrations:
1: Chorley & Handford; 3-6, 8-11: Peter Mackinven; 7: David Wilde; 2, 12-14, 16,19: Graham Gaunt; 15, 17, 18: Jon Carver

19. Inside a glass stair tower.

Lille Grand Palais: Zenith/Congrès/Expo

Rory McGowan Robert Pugh

Euralille

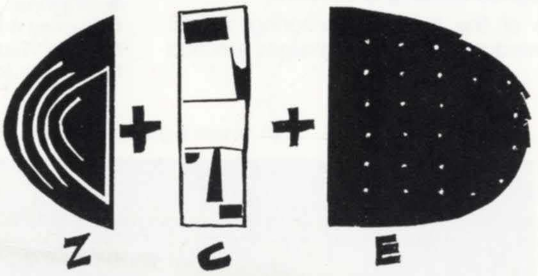
The vision of Lille's Mayor, Pierre Mauroy, was to see that the Channel Tunnel and the TGV network would make his city the 'centre of gravity' of Northern Europe. The chosen architect, Rem Koolhaas, imagined Lille as a 'Virtual City' of 100M people, and with Ove Arup & Partners masterplanned its new heart, the 250 000m² 'Euralille' commercial development. This design team was subsequently appointed for Euralille's major public building, the 50 000m² Lille Grand Palais entertainment, conference and exhibition centre. As long as the Eiffel Tower is high, this huge building was constructed for only £680/m² after just 19 months on site, and opened in June 1994.

1. Aerial view to the south, with inset 2. showing the Lille Grand Palais in the foreground, and the Euralille commercial centre and TGV station beyond.

Lille Grand Palais

The building has three main elements, arranged above a 1300-space integral underground car park:

- ***Zenith:***
  A 7000 (5000 seated) capacity rock concert hall/convention centre
- ***Congrès:***
  A 20 000m² conference centre on five floors including three lecture theatres of 1500, 500, and 320 places, each with simultaneous multi-language translation and delegate voting; 12 meeting rooms of 40-80 places, also with language translation facilities; a 1000-place banqueting suite; exhibition spaces of 2600m² and 1650m²; and administration accommodation.
- ***Expo:***
  A 20 000m² fully serviced exhibition centre subdivisible into three separate halls.



3. Conceptual plan of the main building components.

Concept

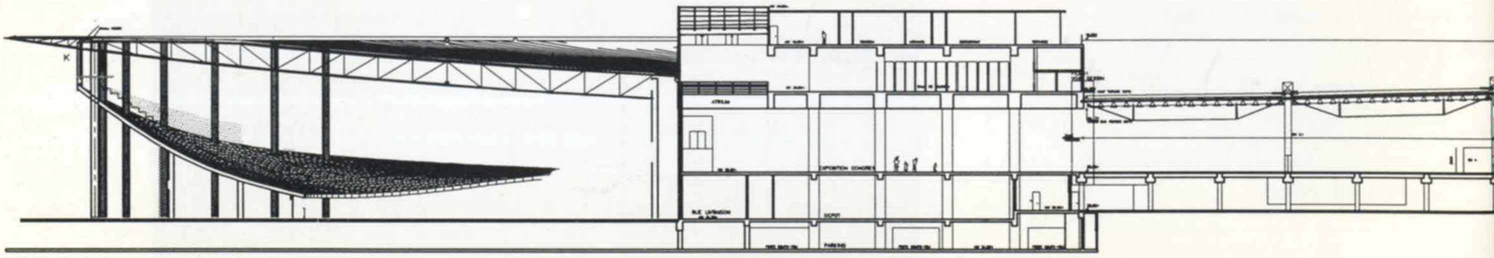
Rem Koolhaas talks about the idea of 'bigness', where scale destroys concerns for fashioning buildings like precious objects with unity of external form and internal homogeneity.

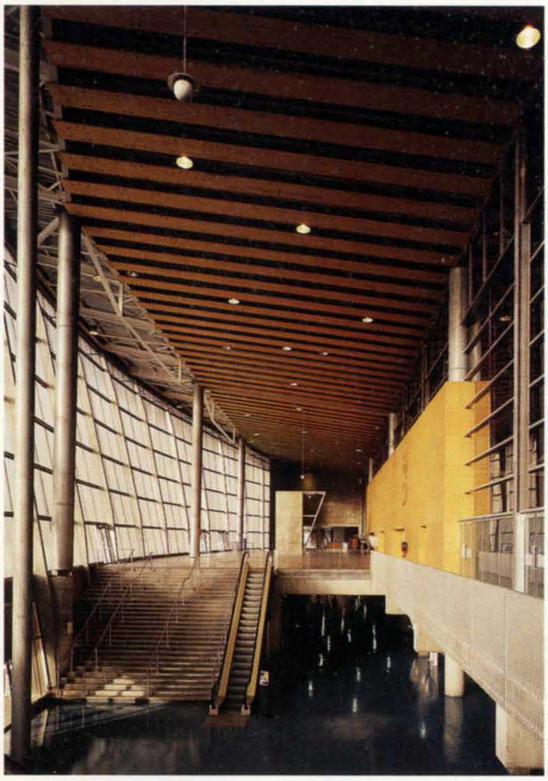
Zenith, Congrès and Expo are thus conceived as separate buildings, but by locating them side by side with a longitudinal inter-relation, and under a single oval roof line, a sense of unity is preserved.

Conceptually, the structure comprises a huge concrete base forming the reception and below-ground parking levels, with elevated and deformed concrete plates forming the auditorium and hall floors in each part, and an oval dish-shaped steelwork roof encompassing the whole plan.

5. Above:
The overlapping ramped main staircase of Congrès, enclosed by inclined stainless steel clad walls.

4. Longitudinal section.





6.
Reception area of Expo.

Lille Grand Palais: Zenith

General

In France, 'Zenith' has become a colloquial term for a multi-purpose, fairly utilitarian hall, most commonly used for rock concerts. Principally, therefore, it requires a large clear span with flexible and generous allowances for suspended lighting and sound systems to suit a variety of stage arrangements. The main acoustic criterion is more to keep the noise in, avoiding disturbance to the environment, than for sophisticated levels of performance.

The other obvious requirement was for the building geometry to give the large audience clear sight-lines to the stage focal point. Zenith's location at one end of the oval is ideally suited to the basic auditorium plan, the radiused external wall naturally focusing on the stage.

Raised gallery floor

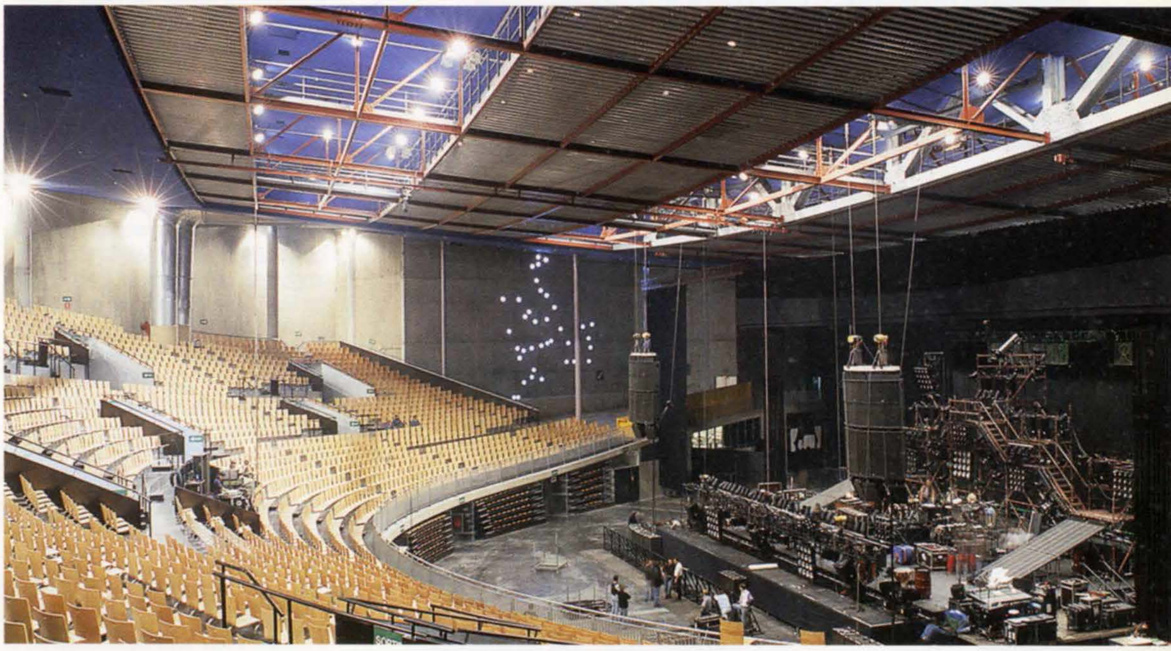
This fans 90° around the curved perimeter and warps +30° to +45° at its rear and 0° to -25° at the front (steep in the centre and shallow at the extremities) to suit the sight-lines. This warped floor was formed as an in situ solid reinforced concrete 'flat' slab supported on the orthogonal grid of columns rising from the parking and reception levels below. It is enclosed by a structural concrete wall and punctuated by openings for steelwork access and escape stairs. Above the gallery floor slab is a steel-framed support to timber tiered seating. The void below this forms a fresh air supply plenum, fed from two large roof-mounted AHUs.

Though the design was simple, attention to its detail was needed for economical and speedy construction.

Curved formwork for the constantly varying and warping geometry would have been expensive and slow. The architect was keen for the soffit to have a 'textured' feature, so a simple formwork and support system was developed, based on the standard 2.4m x 1.2m ply sheet but with an articulating spacer piece adjustable to suit both the radial and warping geometries.

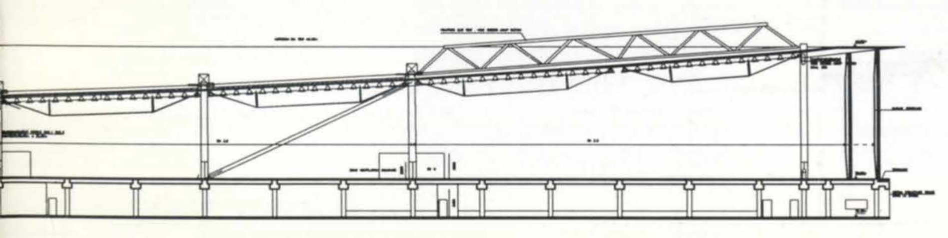
The contoured pattern of repetitive articulating panels proved an ideal solution for contractors and architect. The slab was cast in two 300m^3, 20-hour, pours, carefully sequenced to overcome the steep slope and avoid cold joints.

Zenith *continues over* ▶



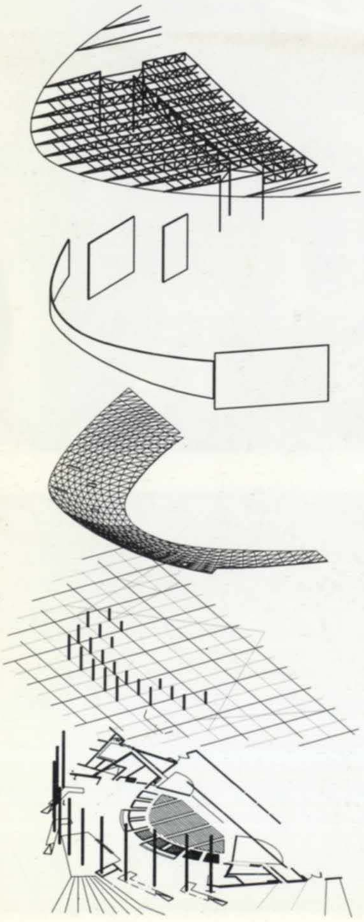
7. Above:
Interior of Zenith, showing gallery seating, and the stage being set up with equipment suspended from the roof.

8. Right:
Articulating modular formwork panels being assembled for the Zenith gallery floor slab.



9. Above:
Warped gallery floor slab under construction:
one half cast, one half decked out with formwork.

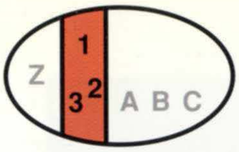
10. Below:
Striking the gallery floor slab to reveal the formwork pattern.



Zenith roof structure

The oval dish shape naturally aided the roof structure, as it deepens in proportion to the increasing span between opposing walls as the centre is approached. The roof is framed by a single 70m-span upstand primary truss bisecting the plan in the deeper part of the dish and supporting a regular grid of 30-40m-span secondary trusses, their geometry dictated by the dish and confined to the roof void. The 70 tonne primary truss, of 5.4m maximum depth, was assembled at floor level from three parts and lifted into place by a pair of mobile cranes. The roof can support suspended loads of 20 tonnes over the stage and 5 tonnes over the auditorium. It incorporates lighting gantries and the acoustic insulating roof, the latter formed by a sandwich panel of plasterboard + void + acoustic panel, integral with external metal decking and covered by thermal insulation and the waterproofing membrane. All steelwork was simple I-sections, weighing in total some 300 tonnes.

11. Left:
Exploded isometric of Zenith structure.



Lille Grand Palais: Congrès

General

The Congrès conference facility is the central slice of the oval, separating and linking Zenith and Expo. Its three auditoria are arranged as 'buttresses' to the other Congrès facilities, all spanning transversely across the oval as a five-storey 'bridge'.

Floor structure

Superimposing the diverse functions on various levels gives an interesting geometric arrangement requiring a unifying structural rationale. Generally, the walls of the various rooms and auditoria form a system of overlapping deep beams (spanning from 16m to 45m) for vertical load transfer. Below the accommodation 'bridge', suspended over the open plan reception and circulation area, the pattern of supporting columns is varied to reflect the load paths and loadings above. A few large columns support the lighter, clearer span areas in the centre of the 'bridge', whereas a denser arrangement of smaller columns support the more heavily loaded 'buttress' areas. These columns are rectangular under the deep beam transfer structures and circular beneath floor areas. The main staircase serving the accommodation rises as a series of diagonal overlapping ramps formed by extensions of the adjacent inclined auditoria floors, their extremities propped with interconnecting inclined columns.The whole construction is generally of in situ reinforced concrete, utilising solid 'flat' slabs for the inclined featured soffits of the auditoria, and precast beams and slabs elsewhere. The front elevation was clad in a 'shingle' (overlapping panel) glass façade, formed by interlocking glass mullions and panels supported at the floor edges. As in Zenith, the main auditoria are supplied with fresh air via plenums in the raised false floors.

Roof structure

The overall 150m x 50m plan divides into three 50m squares at roof level. Two are clear-spanned by steel trusses - over the large lecture theatre and the banqueting hall - and the other by simple steel framing above the administration offices.

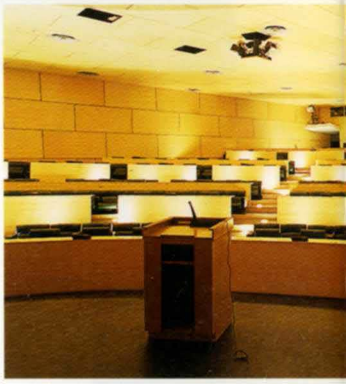
To assist the room acoustics, the altitude and geometry of the trusses over the large lecture theatre are varied to give a pattern of irregular roof planes, further subdivided into smaller irregular geometric planes of corrugated translucent polycarbonate suspended ceiling. Simple I-sections were generally used; total weight of steelwork in the Congrès roof was approximately 200 tonnes.

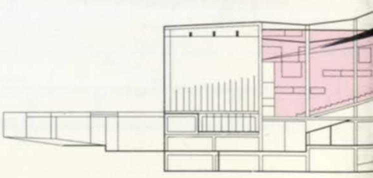
12. Right:
Section of Congrès accommodation 'bridge'.

13. Above:
Interior of 1500-place lecture theatre, showing transparent articulating suspended acoustic ceiling.

14. Right:
Interior of 500-place lecture theatre.

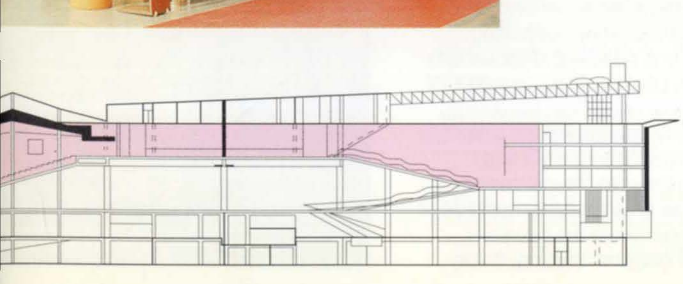
15. Below:
Interior of 320-place lecture theatre.





16. Above:
Support structure to the Congrès 'bridge' under construction.

17. Left:
Entrance and reception area of Congrès, illustrating the simple approach to finishes.



Lille Grand Palais:
Expo

General

The single large hall of the Expo exhibition centre is sub-divisible into three smaller spaces, each c.48m x 150m. Separation is by a heavy moveable acoustic partition at one line and by lightweight demountable partitions at the other. Visitors arrive from a split-level reception at the front of the building; vehicle access direct onto the floor is from the rear. For such a large space, internal fire escape stairs were required mid-plan, and these descend to a protected route to the outside within the parking space below. There is separate visitor and exhibitor parking below the exhibition floor.

Each hall is in modules of 24m x 15.6m, the 24m bay allowing a typical layout of 3m stand + 6m aisle + 3m stand + 3m stand + 6m aisle + 3m stand. The two aisles provide a one-way vehicle access and return circulation route during exhibition set-up and demount.

Floor structure

The floor, suspended over the parking level below, is designed to support 15kN/m^2 in two halls and 30kN/m^2 in the third.

The exhibition stands are serviced by pairs of floor boxes (one offering 'wet services' - water, drainage, compressed air - and the other 'dry', eg power and communications) on a 9m x 9m grid to suit the standard exhibition set-up module. As the floor was suspended, distribution was at high level from the parking floor below and fully accessible. All floor boxes were designed to give appropriate fire separation between the parking and exhibition levels.

The reinforced concrete floor slab, supporting the heavy imposed loads onto the 8m x 7.8m (car park) column grid, was formed by unidirectional primary beams and a floor stiffened by secondary ribs, all precast in repetitive elements to speed construction.

An in situ topping, impregnated with a coloured surface hardener and power-floated to give a resilient surface, incorporates floor heating pipework.

The perimeter walls to the ground floor areas are of in situ concrete, coloured black and cast in rubber lined formwork to give a mock stone effect. These moulded rubber modules (c1m x 1m overall) were designed to have numerous patterns simply by rotating the mould block over the height or length of the wall. Edges and corners were formed by regular truncated moulds.

18.
Exhibition Centre interior in operation. The braced rail below the ceiling supports the heavy acoustic partition, open here to utilise the combined hall area.

Expo *continues over* ▶

19. Expo façade.

Roof structure

The exhibition hall roof design was driven both by the function of the space and by the geometrical opportunities of the architectural form. Architecturally, a thin dished plate offering a uniform smooth soffit was the goal.

Geometry, services integration and fire considerations were the main defining issues, and were addressed as follows:

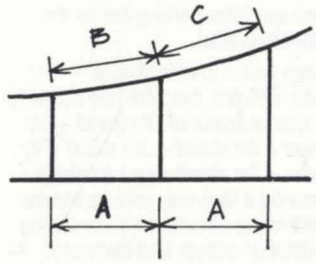
Geometry

One difficulty was in applying simple element repetition to the dish shape, which was defined by a toroidal geometry developed to best fit the required plan and elevation dimensions. The distances from an origin point are different for horizontal and inclined planes, and the angle of incline also increased with distance from the origin.

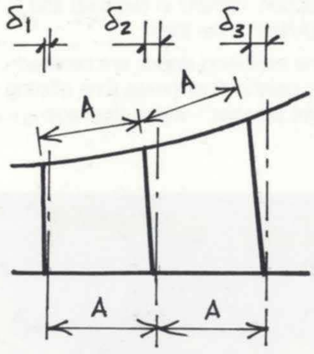
Consequently, with an orthogonal column grid every roof element would be of different length.

This was simply resolved by making all elements a standard length and overcoming the dimensional discrepancy between the grids at floor and roof levels by inclining the columns to connect the translated points. The discrepancy varied from zero at the origin, the low point of the dish with 9m high columns, to 500mm at its extremity, where the columns are 19m.

The resulting almost imperceptible inclination was a subtlety that delighted the architect.



a) Variable roof structure if columns vertical.



b) Constant roof structure with inclined columns.

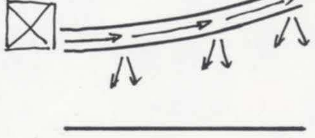
20. Influence of geometry.

Services integration

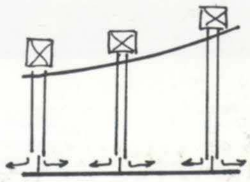
Various HVAC systems were considered - high level versus low level supply; single plant with distributing ducts versus distributed plant and no ducts. Two issues dominated the choice of solution. Firstly, in a tall space only the low level is occupied, so it is sensible and energy-efficient to provide environmental control only where necessary - at low level.

Secondly, distributing ductwork would add cost and space in the roof. Thus individual AHUs sitting on top of the columns were chosen, directly supplying air via displacement ventilation through low-level integral grille diffusers at the bases.

Heating is underfloor, so the only high-level distribution is the power and chilled water connecting the units. With plant sitting directly on columns and no major distribution, the roof structure could be designed solely from structural, functional and architectural considerations.



a) Thick roof if services-integrated roof plate.

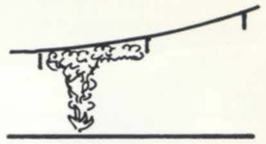


b) Thin roof with services-free roof plate.

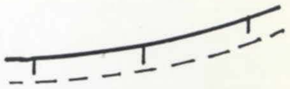
21. Influence of services.

Fire considerations

The principal conflict in finding a solution was between the desire for a uniform plane curved surface, ie: moulded like concrete, and the likelihood that the cheapest structure for a long-span 'warehouse' roof would be steel-framed. The surface area was 20 000m², which raised another issue: fire regulations required ceiling curtains, forming 1000m² reservoirs at least 500mm deep to control spread of smoke. Such fixed features would disrupt the soffit, and if disguised by a false ceiling the regulations required it to have 50% opening to avoid fire protection for roof steelwork. Architectural and cost grounds also eliminated a false ceiling, so a voided structure at least 500mm deep, offering a 50% solid soffit arranged to suit the curved form, was the nearest thing possible to a smooth surface. Various component/materials combinations were considered, including metal decking, steel sheet and plywood. Arups proposed plates of timber forming a slatted ceiling, and the idea developed into triangulated composite trusses - the upper booms and bracing in steelwork, and the lower boom a plate of custom-made laminated timber joined to the steel by bolted split ring shear connectors. Rem Koolhaas loved it and called it 'the Arup roof'. This design was cheaper than more conventional solutions, given the constraints, a fact borne out by the contractor's scrutiny.



a) Irregular surface if smoke curtains below solid soffit.



b) Smoke curtains within perforated soffit.

22. Influence of fire.

Roof layout

The secondary composite trusses are at 1.5m centres with 750mm wide timber plates (ie 50% solid) spanning 15.6m onto primary beams; these in turn span 24m back to the columns. It was felt that the short span was more suitable for the composite trusses and the resulting 750mm overall depth satisfied the smoke reservoir requirements, while keeping the roof construction relatively thin. However, the 24m-span primary beam clearly had to be deeper than this. To minimise disruption to the soffit line, tie beams were used. A 500mm deep I-beam, its web forming the smoke curtain within the depth of the secondaries, was reinforced by a tie frame downstanding below the general soffit line. The way these ties appeared below the otherwise uniform soffit, marking its primary lines of strength, also appealed to the architect.

The columns on the 24m x 15.6m grid were 900mm diameter tubes to suit the air supply volume requirements. Each tube changed to a cruciform section at the base to accommodate the four quadrant-shaped diffuser grilles, and was galvanised inside and out for durability.

The roof plate thus comprised a primary tie-stiffened beam and secondary truss grillage, supporting metal decking, insulation, and the waterproof membrane back to the columns. The columns protruded above this plate to connect to external steelwork, supporting AHUs, and providing diagonal plan stability bracing. This separation of external bracing from supporting roof frame maintained the simplicity of member arrangement and connection, with the column head acting as an articulating nodal point to accommodate the geometry. Internal diagonal bracing, boldly exposed on the hall sub-division lines, completed the stability system.

At the perimeter where the orthogonal grid meets the radial outline of the oval and an undulating façade line, the standard rectangular bay was stopped and substituted with a standard radial bay of propped cantilevers. This gave the roof plate a sharp leading edge, and a primary mullion support to the simple profiled metal and polycarbonate wall cladding. Late in the day the client required that the end hall have a clear span of 48m, instead of the typical 24m.

Rather than change the typical roof system and alter the appearance, the central column was omitted and an external truss provided to pick up the support point.

Due to the unusual nature of the composite timber trusses, tender documentation was set up to allow the contractor to develop the fabrication details, and include for prototype load testing. This, and their construction, are described in the adjacent panel: 'Composite timber trusses'.

The total weight of steel in the Expo roof structure, including columns and mullions, was c800 tonnes.

Composite timber trusses

Particular attention had to be paid both to ultimate capacity and durability. While steel and timber as structural materials are individually well understood and covered by codes of practice, their composite use is rare, and possibly unique in the arrangement employed here where the timber is in permanent tension. The main considerations to be taken into account were how to fabricate the thin timber plates, how to attach them to the reinforcing steel frame, and the effects of internal moisture movement on their internal stresses.

In the circumstances, prototype load testing was recommended and successfully undertaken, giving confidence before production of the 750 trusses needed - which totalled some 11.5km in length.

Key points

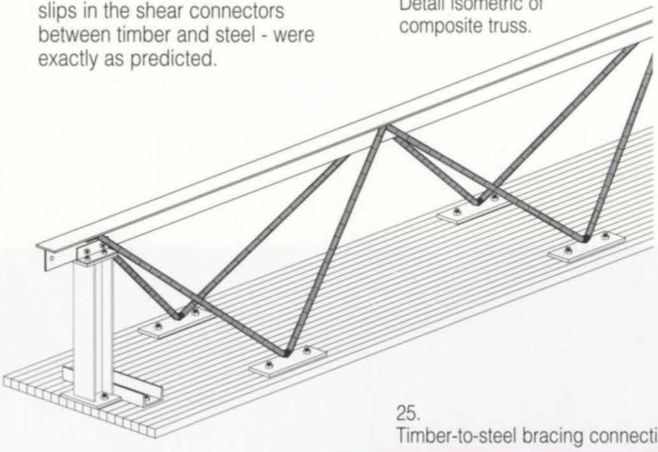
- Shrinkage strain from moisture movement in the thin timbers could lead to splitting if bolted directly to a continuous steel plate. This was dealt with by connecting them at intervals to diagonal bracing, which allowed an inbuilt flexibility for relative movement between the two materials.
- Potential for timber warping was minimised by using a thin section, the difference in moisture content and movement between two such close faces being negligible.
- The timber was treated to protect against high moisture content variation between the exposed construction phase and the dry internal permanent condition.
- The glued laminated timber plates were 15m long but only 35mm thick, formed from Swedish pine sawn joists, with staggered butt joints in the length, and 17 sections across the width. Quality was controlled by sample load testing of finished pieces in tension and bending.
- Prototype trusses were load-tested comparing deflections at service and ultimate loads with calculation predictions, and over a period of time to assess any potential for creep.

Temperature was taken into account in comparing the results as the different coefficients of expansion of the materials caused curvature in the trusses.

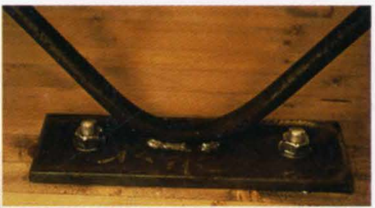
The results - allowing for permissible slips in the shear connectors between timber and steel - were exactly as predicted.

- A truss was tested to failure, which showed a capacity of 3x the service load condition (the codified requirement being 2.5x).

Failure was by the steel boom and bracing elements buckling under compression, as intended.



23.
Detail isometric of composite truss.



25.
Timber-to-steel bracing connection.

24. Prototype trusses ready for load testing.

Conclusion

Arups' involvement, though limited on the services to the concept, continued for the structure throughout the project. The design, being effectively for three separate buildings in one, presented more challenges and involved more exploration and multi-national collaboration than commonly involved in one project. However at its heart the building is simple in concept and this principle has, it is hoped, been maintained through to its detailed resolution.

This simplicity, coupled with basic but carefully thought-out finishes and details, was essential for the pre-requisites of low budget and tight construction timescale which were achieved.

Reference

(1) LE BOURVA, S., *et al.* Euralille: the TGV station roof. *The Arup Journal*, *30*(2), pp.3-6, 1995.

Credits

Client:
Euralille

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Sodeg Ingénierie (services & co-ordination)

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Agence Van Santen

Acoustics:
Tno - Bouw

Scenography:
Agence Ducks

Economist:
Cabinet Gaillet

Bureau de Contrôle:
Socotec

Planning:
Gemo

Main contractor:
Dumez-Quillery SNEP

Steelwork contractor:
Baudin Chateauneuf

Illustrations:
1, 9, 10, 16, 26: Photo Poteau;
2: R. Lesquin; Logo, 3: Nigel Whale
4, 11, 18: OMA
5-7, 13-15, 17, 19, 27: Peter Mackinven
8: Cecil Balmond; 12: Jon Carver
20-22, 24, 25: Robert Pugh
23: Sam Hatch

26. Below: Erection on site.

27. Right:
General interior view of roof structure, showing composite timber trusses, supported on steel tie beams, with tubular columns serving displacement ventilation at low level. Diagonal bracing for stability was architecturally required to be expressed in the interior.

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