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Ove Arup Partnership
13 Fitzroy Street
London W1P 6BQ

Tel: +44 (0) 171 636 1531
Fax: +44 (0) 171 580 3924

Editor:
David J Brown

Art Editor:
Desmond Wyeth FCSD

Deputy Editor:
Beth Morgan

Editorial:
Tel: +44 (0) 171 465 3828
Fax: +44 (0) 171 465 3675

Front cover:
Main entrance of Yapı Kredi Bank, Gebze, Turkey (Photo: Peter Cook)

Back cover:
New Jersey Performing Arts Center rotunda (Photo: Fred Charles)

Yapı Kredi Bank Operations Centre Complex, Gebze, Turkey **3**

Hamdi Ataoglu
Noyan Sancar
Brian Forster
et al


Peter Cook

Yapı Kredi Bank, one of Turkey's largest private banks, wanted its new operations centre, on a greenfield site 50km from Istanbul, to provide a spatially flexible, attractive, and technologically state-of-the-art working environment for its 2000+ staff. Arup Mühendislik ve Müsavirlik Ltd Sti (Arup Istanbul) was appointed prime agent, heading a design team which included Arup structural, building services, fit-out, façade, communications, fire, landscaping, and infrastructure engineers, acousticians, and project managers, as well as architects John McAslan & Partners.

Byzantine Fresco Chapel Museum, Houston, Texas **12**

Ignacio Barandiaran
Varughese Cherian
Ray Quinn
Andy Sedgwick


Paul Warchol

To house the restored fragments of two Byzantine frescos from a chapel in Cyprus, the Menil Foundation of Houston commissioned a small building which would also function as a consecrated Greek Orthodox chapel. The architect François de Menil designed a Glass Chapel within an outer 'reliquary container', for which Ove Arup & Partners' multi-disciplinary team was responsible for the structure of the outer building and the support system for the Glass Chapel, as well as the lighting, acoustics, and building services.

Enid A Haupt Conservatory, New York **15**

Liam O'Hanlon


Fred Charles

The City of New York commissioned Arups to undertake a thorough renovation of this 19th century conservatory, the largest of its kind in the USA. Extensive investigations of the original building were necessary, and following this Arups designed a completely new glazing system as well as other works including foundations, rebuilding of masonry walls and roofs, and restoring the deteriorated and damaged iron and steel structure.

New Jersey Performing Arts Center **19**

Jacob Chan
John Gautrey
Nancy Hamilton
Alan Locke


David Street

As the centrepiece to its inner city revitalisation programme, the City of Newark envisaged a performing arts centre to rival the best in the world. Barton Myers was engaged as architect, and he requested Ove Arup & Partners California to be the project building engineers. The Center comprises a large and a small auditorium plus extensive community, rehearsal, and administrative areas. Arups designed the structural and building services systems to the most stringent acoustic isolation criteria.

Wenko-Wenselaar Headquarters, Hückelhoven **25**

Michele Janner


Michele Janner

Arups' German practice, Arup GmbH, carried out the building physics analysis and designed the structure for this 18 000m² headquarters building complex, including office accommodation, storage, packaging, and loading/unloading facilities, for a leading German household goods company.

Yapı Kredi Bank Operations Centre Complex, Gebze, Turkey

Ercan Agar
Tufan Aksoy
Hamdi Ataoglu
Mehmet Ozaltinok
Vahap Samanli
Noyan Sancar
Harika Uyanik

1. Bridge leading to main entrance. View from south-west.

Introduction

Yapı Kredi Bank (YKB) is one of the largest private banks in Turkey. Its headquarters was built in 1990 at the YKB Plaza in central Istanbul, but within a few years further expansion was needed and YKB decided to move its data centre and major banking operations to a new site at Gebze, some 50km south east of Istanbul. The site is located within the municipality of Güzeltepe off the Istanbul to Ankara motorway, on a steeply sloping site overlooking the Sea of Marmara.

With the initial contacts starting in July 1993 and contract finalising in December 1993, Yapı Kredi Bank appointed Arups' Istanbul office, Arup Mühendislik ve Müsavirlik Ltd Sti (Arup MMLS) as the prime agent for the project. John McAslan & Partners in London (then Troughton McAslan) was recommended and appointed by the client as the lead architect. Metex Design Group of Istanbul was commissioned as executive architect and Tabanlıoglu Architects as interior designers.

The project was the first of its kind in Turkey, and easily one of the largest bank operation centres in Europe. For these reasons, development of the initial brief proved a major task in itself. Working closely with the client, Arups produced the Plan of Work document on 11 February 1994; it defined the firm's role in the project, as well as the formal relationships between all parties involved.

The project was realised in stages: master plan, concept, scheme, enhanced detail design, tender, and finally the execution phases. The initial stages of the design took place in London, apart from site infrastructure and building structures which were largely undertaken in Istanbul.

The skills of several London-based groups - Building Engineering Group 3, Arup Façade Engineering, Arup Communications, Arup Fire, Arup Acoustics, and Project Management Services - were brought together with the architect during the early days of the project. The building's catering and security needs were handled by UK sub-consultants.

Effective project controls ensured proper co-ordination of these groups' input.
The work then moved to the Istanbul office for detail design, where all engineering, architectural, and management activities were centred until completion.

A multinational, multi-disciplinary team of over 40 engineers and architects - including the lead and executive architects - was formed and carried the project through the execution stage successfully. Arups was also later commissioned for a second phase consisting of two additional blocks of 7000m^2, serving mainly as the training and call centres for YKB. Construction of the main building was already under way by then, but the design and procurement activities were successfully dealt with, avoiding any setbacks to the scheme.

The concept

YKB's brief called for a flexible building, capable of adapting to the bank's quickly-changing requirements. It specified that the design should encourage interaction between the different departments in the Centre, and create a pleasant working environment for their staff. In conformity with the image of YKB, the complex needed to be prestigious and long-lasting, and exemplify good architecture and engineering, thorough quality control, and precise execution. The brief also emphasised the need for a high level of security throughout the site. These requirements, and the site's natural features, formed the starting point from which the design was developed.

The gross dimensions of the roughly triangular site are 550m by 450m, its 230 000m^2 sloping from +199m in the east to +140m in the west, with the Sea of Marmara lying to the south west. Natural slopes and gullies divide the site into three distinct areas: the curved hillside in the east, with its back to the motorway overlooking the Sea of Marmara; the more gently sloping area facing the motorway and bounded in the south by the principal access road; and low-lying ground in the north of the site, which is now allocated for community use. The Operations Centre is situated on the first of these areas - the prominent hillside in the east - thus taking full advantage both of the best views and environmental conditions.

Separating the Centre from the principal points of access onto the site is a natural gulley running around its perimeter. Two reinforced concrete bridges span the gulley, facilitating control of traffic in and out of the Centre via three entry points: the main entrance, used by all employees and visitors; the service entrance, used by security trucks and service vehicles; and the 'Helipad' for arrivals by helicopter. Additionally, the landscaped parking area is controlled from security control points at the main entrance.

2.
General view of construction site, September 1996, facing east.
The two Phase 2 blocks are at the rear, with the motorway in the distance.

3.
Site plan.

The architectural master plan outlined four stages of development. As constructed, the first two stages comprise a 44 200m^2 building area with 10 35m square blocks, most of them three storeys high. Some blocks have a central 10m square courtyard - a form inspired by traditional Turkish architecture. This feature maximises daylight, as does the Centre's south-west orientation.

The blocks are arranged on a grid with 10m wide internal streets - again inspired by traditional Turkish covered streets - separating and connecting them. As well as serving as circulation space, the internal streets are focuses for social activities - decorated with tropical plants and furnished with street cafes and shopping stands. Stair and lift towers are situated at the street intersections, providing vertical circulation with access to all blocks and toilet pods. Link bridges, of structural steel and glazed panels, connect certain blocks directly at upper levels.

Effective project management

From the project's initial stages, the team focused on establishing stringent controls over quality, time, and cost (roughly in that order). Another essential issue was to develop the brief in detail.

The management activities, tools, and organisation adopted for the project addressed all these aspects.

Progress of the design was reported and discussed through regular meetings and work sessions with the client's project group, and each phase of design was documented for approval by the client. Quantity surveyors were an integral part of the design team throughout, and the initial budget was continuously updated to reflect the financial consequences of each design phase. Value engineering studies were made to achieve the optimum balance between designers' aspirations and the overall project cost.

The Final Cost Plan was produced in February 1995, and was approved as the budget control for subsequent procurement activities. Planning studies for all phases of the project, including design, started from the early masterplan days and were developed as the works progressed, reaching a level of over 6000 concurrent activities on peak days.

The client's design requirements were very clear - for a utilitarian, flexible, efficient, but user-friendly building with contemporary architecture to reflect YKB's business aspirations. This was basically a design issue, but when coupled with time, cost, and quality control, defining the right project execution strategy became essential to the scheme's overall success. During the many work sessions with the client's team, Arup MMLS's role as the Prime Agent developed to cover aspects of project management and execution stages, in addition to those for the design stage.

It became apparent that the usual procurement method - one main contractor in charge of overall execution - would be unsuitable, mainly because the works would have to be tendered as one big package after the design and production information for the whole project was complete. This would have resulted in a later construction start date, as compared to a multi-packaged scheme where work can start as the relevant information becomes ready.

Management contracting not being common in Turkey, it was decided that the main contractor would be responsible for civil and building structure works, and would also provide overall site management, planning, and supervision for the other works contractors, with Arup MMLS as engineer. Works contractors were appointed jointly by the client, the main contractor, and Arup MMLS in a competitive environment.

The principles of the project execution plan were set forth as follows:

- Provide the means for establishing a competitive procurement environment to get the best companies on board, at the least reasonable cost.
- Define the work in sufficient detail through tender drawings, schedule of items, and a series of comprehensive preliminaries and specifications to avoid unnecessary risks being built into the bid prices, thus eliminating as far as possible adverse effects of unplanned events, including claim issues.
- Develop effective tools to continuously monitor time, quality, and cost issues during execution with the participation of all contractors.
- Establish procedures whereby the client, the main contractor, and Arups would work closely together, with the client as final decision-maker, supported by Arup MMLS as engineer, and the main contractor as the executive body for the construction.

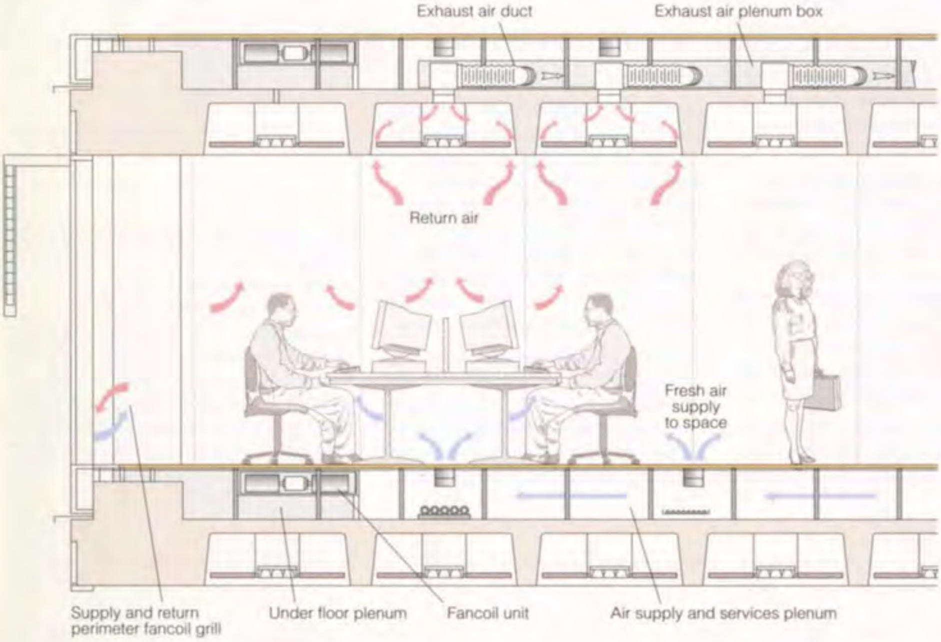
The client's project team - led by Executive Vice President Faik Türkman - and legal department worked together with Arups' project management team to establish the contract structure for the project. By the end of 1994 it was possible to appoint the main contractor for the job. During the first half of 1995 the works contracts for the major packages were awarded. Remaining works packages were tendered during 1996.

The main contractor also undertook site quality control, establishment of site plant and facilities as well as checking the interim payments for the works contractors. Arup MMLS had staff on site to monitor these activities. Additionally, Arups' design team reviewed and checked all working designs implemented by the works contractors for each of the packages.

Arups' management team produced progress reports, control budget updates and provided advice as necessary to the client's project team so that each management decision would be based on clear understanding and analysis of the developments in the project. Early budget and project duration predictions of Arups were satisfactorily on target, and the client's first group was able to move to the Operations Centre in the beginning of September 1997. By the end of 1997 the number of staff exceeded 1200.

4.
Interior of glazed bridge to main entrance.

5. South elevation.



6.
Typical building cross-section showing raised access flooring, coffer infill panels, M&E services, and lighting.

7. Stair tower.

The structural system

While the low height of the blocks and good subsoil conditions would suggest a relatively simple structure, the high stability factor required by the presence of the main data centre of YKB, and the site's location in an area of high seismic risk (corresponding to UBC Zone 4) necessitated special measures and precautions.

The structure is designed to withstand minor earthquakes without structural damage. In the event of major earthquakes (estimated to occur once every 500 years), plastic hinges in the beams will absorb the seismic energy without collapse. The cladding panels and movement joints between the blocks are designed to accommodate the lateral displacements between the blocks.

Steel structures including the stair towers, the link bridges, and the toilet pods were also designed to accommodate seismic displacements within the vertical and horizontal deflection limits.
All WCs and building services were removed from the block floor plates, and the exterior reinforced concrete access bridges were designed to comply with both ASSHTO and Turkish Bridge Codes.

Typically, each structurally independent block comprises three reinforced concrete waffle slabs providing a floor area of 1250m^2 where there is no inner courtyard, and 1054m^2 where there is an inner courtyard. The waffles are 1.5m x 1.5m with an overall depth of 600mm.

Vertical loads are carried by 16 columns on the perimeter and four columns at the inner courtyard locations, with lateral stability provided by the perimeter moment-resisting frames only.

The columns are 4.5m high at the entrance level floors and 4m at all other floors. With the raised access flooring installed, the clear heights are 4m at the entrance floors and 3.5m at all other floors.

Office space

Most of the office space is open plan, although certain bank departments also required cellular offices. The space planning exercise was carried out by Arups and the furniture firm Ahrend, in consultation with YKB. Generally, each of the floors has an SER (sub-equipment room) at the side of courtyard. The meeting rooms and group service areas (for photocopiers, storage space, fax machines and so on) are located on both sides of the SER.

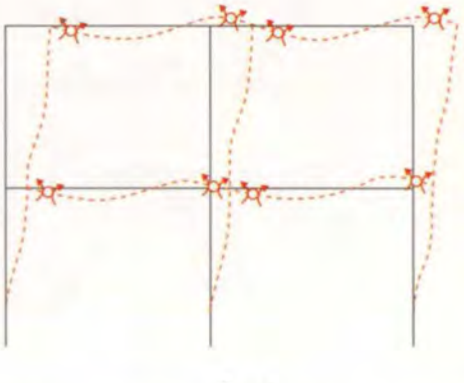
A typical office floor consists of:

- Net internal area: 1040m^2
- Primary circulation 1.5m wide corridor: 170m^2
- SER, meeting room and group service area: 50m^2
- Available space for work-stations: 820m^2.

Work stations are generally arranged as four 'L-shapes', put together to form a cross, leaving a 1.5m corridor for circulation. EVP work stations are separated with 1.6m high screens, whilst there are round tables for staff group meetings on the dead ends of the floors. Storage cabinets at the same height as the desks are located on both sides of the circulation corridors.

Each office floor was originally conceived to accommodate 100 staff, allocating 10.5m^2 per person. However it became clear during the more detailed space planning stages that 120 to 130 staff could comfortably be accommodated because of the furniture selected.

Main text continues on page 9 ▶



8.
Plastic hinge mechanism for absorption of seismic energy without collapse. Members are detailed so that plastic hinges form at beams rather than columns. This 'strong column / weak beam' approach is a requirement in all modern earthquake codes. The resulting collapse mechanism would then be as shown.

Design of the street roofs and glass walls

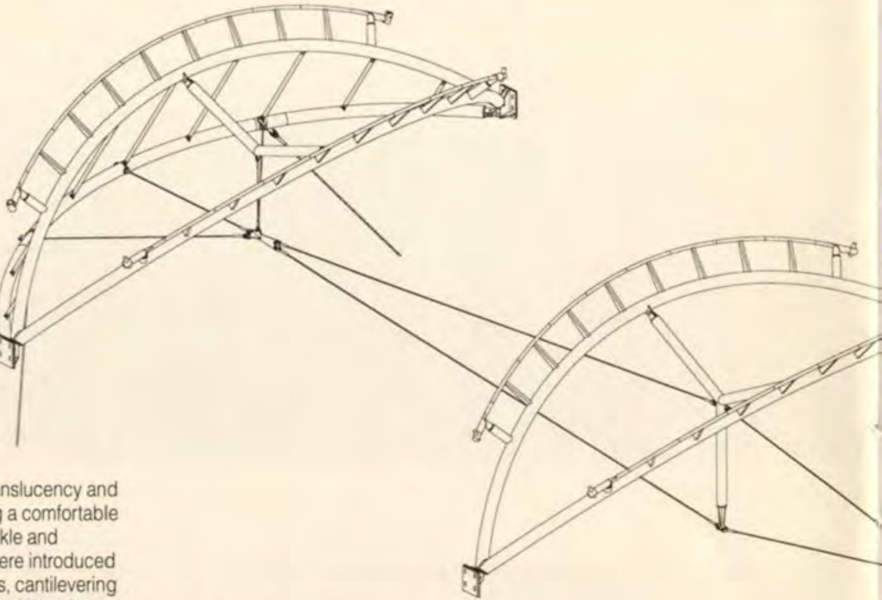
Brian Forster

The streets between buildings are enclosed with textile roofs and glazed end walls. They are part of the enclosing skin of the whole complex and enable the streets to be a climatic buffer zone between inside and outside temperatures. Given the seismic nature of the area it was important that both roofs and walls should accommodate the independent sway movements of individual buildings (± 60mm in X and Y directions).

The design initially considered each roof and wall as a stiff flat plane attached to one building, and on the other free to slide in X and Y directions to avoid structural coupling. However as this type of arrangement was examined, concern developed over the architectural legibility of the junctions between glazed wall, building façade, and roof. Was there an alternative to sliding movements? Thoughts turned to the obvious advantages of a three-pin arch and ultimately progressed to the two-pin arch.

The street roofs

Displacement of buildings relative to one other along the streets causes a 'racking' action on plan and so a roof construction with low shear stiffness and geometric flexibility was desirable and provided part of the justification for using a textile membrane. The basic scheme was developed over two weeks, in which structural solutions responded to architectural needs and desires.

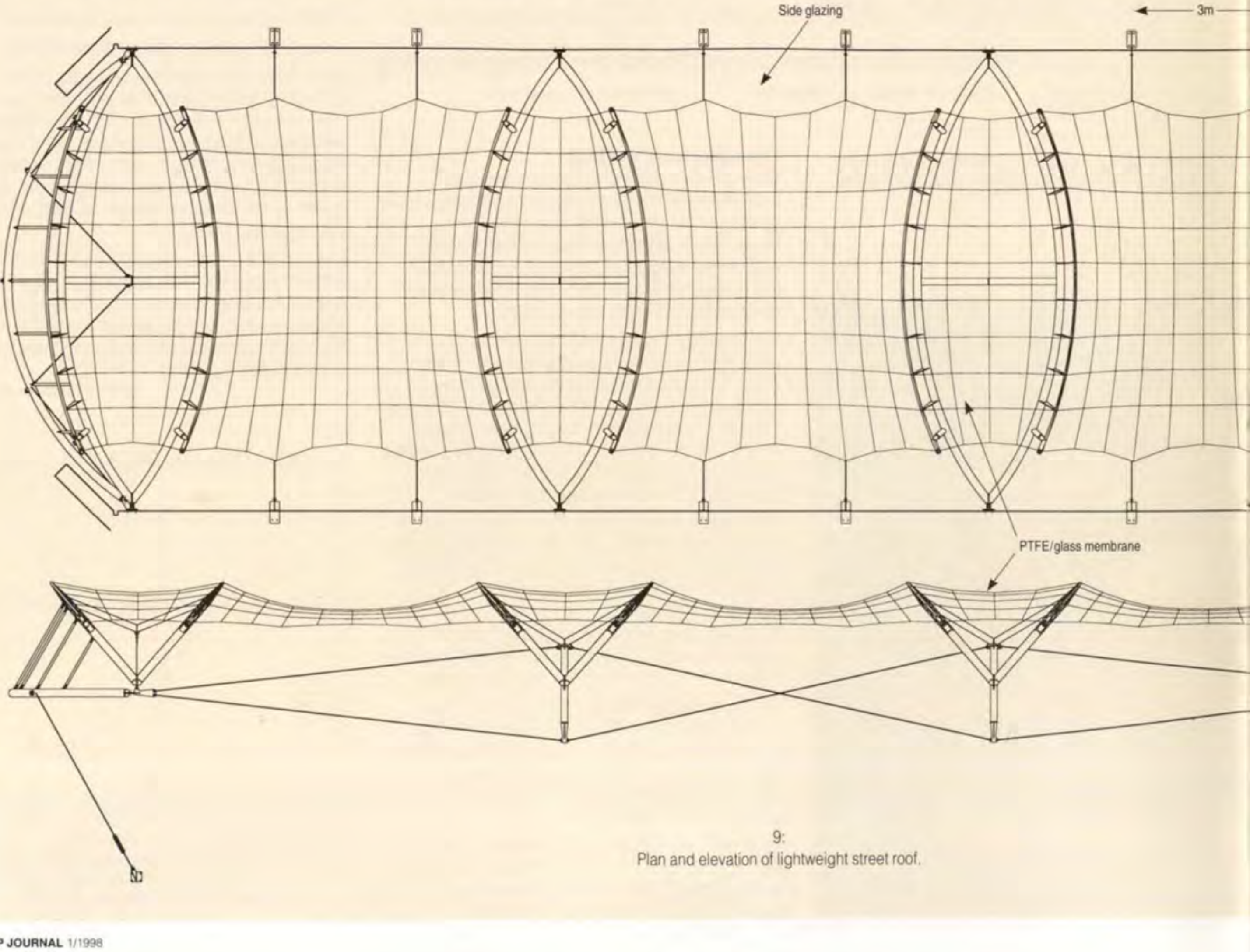


The membrane has 13% translucency and acts as a diffuser producing a comfortable glare-free light. To add sparkle and contrast, strips of glazing were introduced along the sides of the streets, cantilevering directly from the buildings and lying in an inclined plane immediately above the arches but below the membrane whose cabled edge oversails it.

The arches were initially thought of as frequent and parallel, with the membrane passing over. Pairing arches together into a 'lemon-wedge' shape enabled the roof and the glazed end walls to have a common curved boundary. The form of the end arches has its origin in the search for ways to enclose the streets at the four-way junction with the stair towers, where roofs sometimes arrive at different levels.

The solution involves a third arch laid in a horizontal plane, linked to the outer arch using inclined tubes which double-up as glazing bar supports. These were set out on the surface of an elliptic cylinder to support framed glass. This end arch assembly is mounted on spherical bearings, allowing it to rock about both X and Y axes. The overturning moment produced by longitudinal membrane tensions pulling onto the end arch ribs is resisted by cables that incline down onto the building façades one storey below.

The membrane tensions across the street go directly onto the buildings via external rigging screws. The membrane is connected only to the end arches and simply bears down over the intermediate ones. The two intermediate arch pairs are pivoted about a single axis accommodating the movements that the buildings impose across the street, and are stabilised longitudinally by cables connected to a 'Y'-shaped lever projecting down below the axis of the arch pivots to form a simple counterbalance. At the end arches the longitudinal tie fans out to react against the horizontal end arches, smoothing out bending moments around the end arch.



9:
Plan and elevation of lightweight street roof.

The longitudinal ties are modestly prestressed to 15kN. In the event of the buildings moving apart, the distance between the crowns of the end horizontal arches reduces significantly more than the amount provided by the prestress strain in the longitudinal tie cables. To compensate for this, and avoid dynamic 'snatch' loading of the structure, pre-compressed springs are provided at the ends of the cable system.

These stacks of disc-springs are tailored to give an appropriate stiffness and range of displacement, and contained within sleeves set into the arch tube itself. In normal circumstances they have no influence on the stiffness of the longitudinal tie, only coming into play with extreme building movement, whilst maintaining a small residual tension in the cable.

Conversely, if buildings move towards each other the force in the longitudinal tie system increases. As they approach what is perceived as an ultimate state of movement the forces in the tie system become large enough to threaten rupture at points in the arches and Y frames. To protect against this a 'fuse' is incorporated at mid-length in the longitudinal tie which will yield and thereby reduce force in the system.

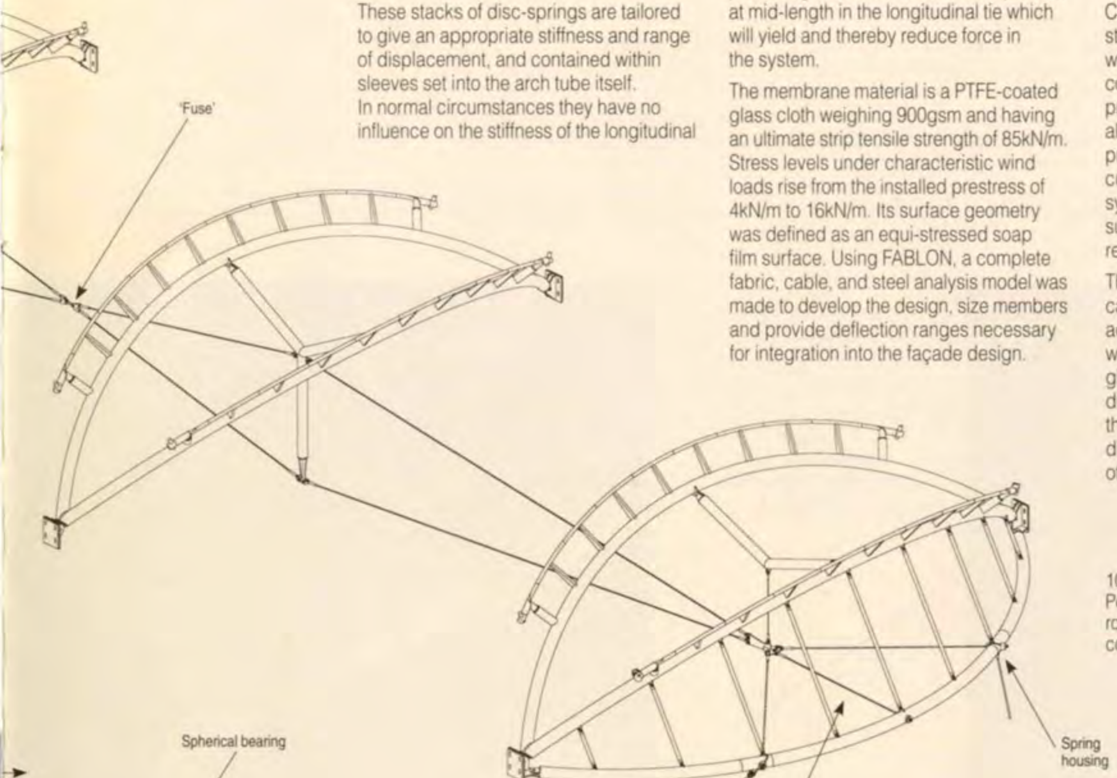
The membrane material is a PTFE-coated glass cloth weighing 900gsm and having an ultimate strip tensile strength of 85kN/m. Stress levels under characteristic wind loads rise from the installed prestress of 4kN/m to 16kN/m. Its surface geometry was defined as an equi-stressed soap film surface. Using FABLON, a complete fabric, cable, and steel analysis model was made to develop the design, size members and provide deflection ranges necessary for integration into the façade design.

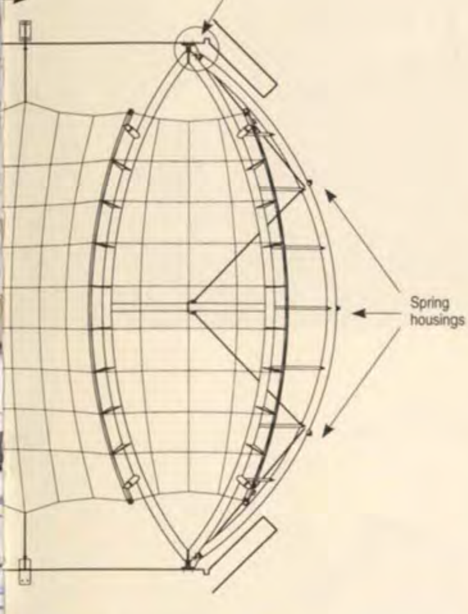
The glazed walls

The glazed end walls are somewhat simpler in action but again use the two-pin arch to absorb the imposed movements of adjacent buildings without recourse to movement joints. The weight of the glass is supported by a curved beam, continuous over three supports, with the panes of glass stacked one on top of another. The vertical edges of the panes are butted together with a sealant joint.

CHS hoops set in horizontal planes at half-storey intervals support the glass against wind forces. These hoops are formed to a compound curve to match the horizontal projection of the roof arch above, and are also supported at mid-span with a slender prop of battened plates. The virtue of a curved beam on a three-point support system is that torsional restraint at supports is not required as torsions are resolved internally within the beam.

The seismic movements of the buildings cause change in shape of the hoops and additional bending. Another consideration was the general warping effect of the glazed surface as a result of the edge displacements increasing from zero at the bottom to maximum at the top. This distortion is absorbed within the elasticity of the sealant joints in the glass.





10.
Perspective of lightweight roof truss system over the covered streets.

11.
Lightweight roof over street from main entrance.

Building cladding

Andrew Hall

Arup Façade Engineering (AFE) were appointed as an integral part of the overall Turkish and UK Arup team to develop the design of the 18 000m^2 of façade and cladding elements with the architect. The five generic areas included infill glazing panels (8700m^2), six glazed end walls (2000m^2), glass block cladding to stair towers (400m^2), stone cladding (1600m^2), and riser cladding (5000m^2). Clear glazing with a 'Low E' coating is used on façades, making the natural environment visible to occupants and also maximising natural daylight.

Post-tender, the cladding, procured using visual intent drawings and technical performance-based specifications, was developed by AFE with Çuhadaroglu, a Turkish cladding contractor, producing project-specific bespoke systems. This route was unusual for the Turkish market, more used to the fabrication and assembly of 'standard' window and curtain walling systems. Beyond the architectural intent, the two key design parameters were the seismic requirements and tight financial constraints. Described below are key issues relating to the two main cladding types.

Infill glazing

Apertures 8.4m wide x 3.4m high in the concrete frame had a series of 3m wide rigid aluminium frames bolted together on site to form complete infill panels. An interlocking aluminium channel frame at the perimeter dealt with concrete tolerances and the accommodation of seismic movements of the primary structure. Weathering relies in all instances on an outer weathering seal and an inner air/vapour seal between which the cavity is drained, ventilated, and pressure-equalised. Within the aluminium framing a variety of clear/translucent double and single-glazed panels are combined with stud-welded anodised aluminium spandrels in response to the variety of adjacent internal functions. Solar shading is provided externally by fixed rigid slatted elements and internally, within the 'streets', by the fixed fabric awnings.

Glazed end walls

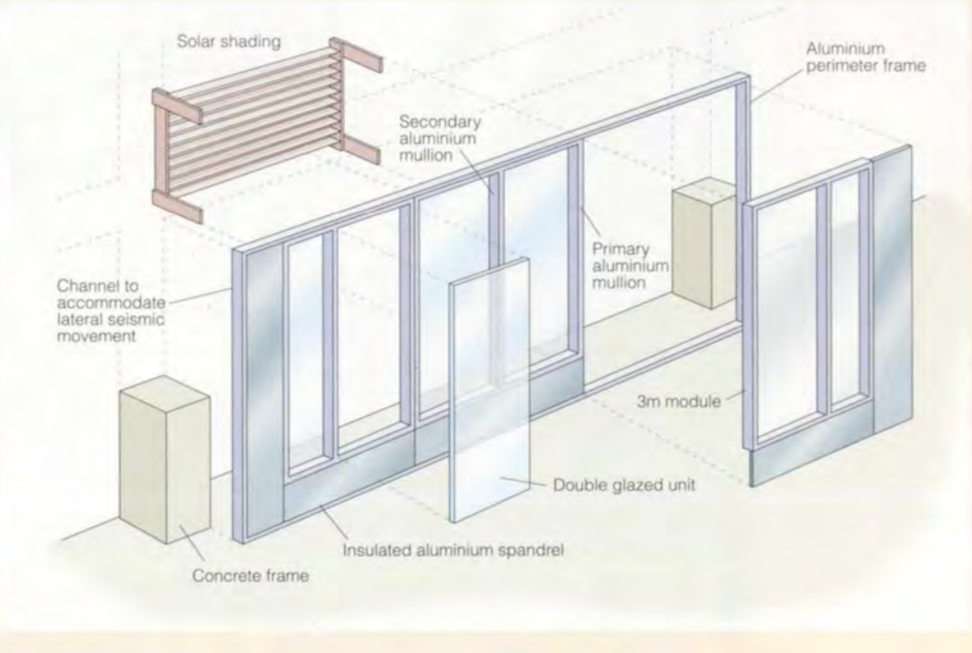
As Brian Forster describes on pp 6-7, the ends of the internal streets are closed by a series of two and three-storey convex and concave single-glazed screens. 10mm toughened glass panels with silicone-pointed vertical joints are supported via extruded aluminium horizontal channels back to a horizontal tubular steelwork structure centrally propped from ground level. The articulated cylindrical form of each wall transforms to a part-conical shape to accommodate seismic movement of the adjacent structure.

During the detailed and subsequent post-tender design AFE were able to maintain close control of technical aspects of cladding, whilst remaining true to the architects' visual intention for each façade element. This relied not only on close liaison with the Arup Istanbul team, but also with the co-operation of the cladding contractor to produce a building which combines the utilitarian requirements of an operations complex with the elegance required by the client. The project represents a bench-mark for future developments in Turkey and illustrates the quality achievable by the local industry.

12 left.
A typical glazed end wall covering the street between the buildings.

13 right.
External glazing to cafeteria and office floors at night.

14 below.
Typical installation of infill glazing panel and external sunshade louvres.



Main text continued from page 5
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Furthermore, several departments needing smaller work-stations could be planned to have much denser accommodation of up to160 persons. These variations in space planning demonstrated the flexibility and efficiency of the raised floor, with the M&E services responding to the occupants' requirements.

The floors have monoblock partition panels that can be easily mounted and dismounted. Partition panels perpendicular to the building façade are solid and the parallel ones are fritted glazed panels. It is easy to change the single-glazed panels to double-glazed, merely by adding another layer of glass onto the frames when a higher level of privacy is required. Boards, coat racks, pictures, and signage elements can easily be installed on the steel partition panels using magnetic hangers.

Mechanical systems

The energy centre block (C3) contains the central plant, with facilities including boilers, cooling towers and water services. M&E systems are co-ordinated both in the raised floor void and in the risers in a repeated and modular fashion. A fully integrated building management system (BMS) monitors the external conditions and optimises the plant energy consumption to provide an energy-efficient and responsive control. There are 1016 control points in the system.

Ventilation

Inside the office buildings a displacement air-conditioning system is used. Air is supplied through a modular extract ductwork network under the raised void of the floor above, propelled through the raised floor plenum by 200mm diameter swirl diffusers, with supply temperatures ranging between 18°C and 22°C (according to the external conditions).

The exposed concrete structure of the blocks provides good thermal capacity, reducing diurnal temperature fluctuations, with overnight cooling compensating for daytime heat gains. Additional perimeter underfloor fan coil units offset additional machinery loads and intensive solar gains.

Primary air is supplied from the basement plant room air-handling units (AHUs), two of which serve three floors of each block. Primary air is not recirculated - the extracted air passes through the heat recovery coils linked back to the AHUs, reclaiming energy and providing a very high air quality inside the building. The AHUs have variable speed drives and two-stage axial extract fans differentiate the air volumes to utilise need in peak winter and summer loads, thus reducing energy consumption.

Fan coil units (FCUs) are located under the raised access floor on the 3m perimeter area. Supply and return grilles are separated by an under-floor plenum which connects the 350mm deep concrete edge beam (necessary for seismic stability). A modular pattern for the FCU pipework connections, and the flexible nature of the raised floor plenum for the swirl outlet locations, create a highly flexible system for the mechanical facilities, and the electrical and communications cabling.
The system has proved sufficiently flexible to accommodate the high office churn rates, with frequently changing furniture layouts and different densities for various floors within the first months of occupation of the buildings.

A dedicated chilled water system serves the Operations Centre and its related functions.

The internal streets are naturally ventilated during the summer and heated to 17°C in winter using convectional heaters in the trenches on both sides of the streets. Glazed end walls are protected from downdraughts by hot air blowing through the curved ductwork. Stair towers are heated by air heaters located in the risers blowing hot air with jet diffusers.

15. Internal street.

Fire protection systems

All floor plates are protected with a wet sprinkler system with a classification of ordinary Hazard Group-1, and each floor plate has two 30m hose-reels and portable fire extinguishers.
The data centres and computer-related equipment rooms are protected by FM 200 gaseous systems. The site is protected by an external fire-fighting ring main with hydrants at strategic locations. Smoke extract from the space is achieved with twin extract fans located in the risers.

Electrical services

High voltage supply and distribution

The main electrical plant is also located in the energy centre block. The main transformers, which back up each other at the rate of 100%, are 2 x 6MVA, 34.5/10kV oil-type transformers, fed from two separate lines by the Turkish Electricity Authority to ensure maximum reliable operation, with automatically controlled top changers to provide stable voltage operation. Secondary distribution transformers are 10/0.4kV maintenance-free, cast resin type. Two such transformers serve the Data Centre mechanical equipment (BC2, C2 and B3 blocks) and are 2 x 2000kVA providing 100% back up for each other. Two similar transformers serve the Data Centre electrical equipment and are 2 x 1250kVA, again providing 100% mutual back up. The other transformers of 2 x 1250kVA capacity - serving A2 and A3 Blocks - are located in A23 plant room. B1 and C1 Blocks are served by a transformer located in BC1 plant room. One 800kVA transformer serves D1 and B1 blocks, located in D1-2 plant room.

All 10kV substations are fed from three 1000kVA diesel generators. The Data Centre electrical equipment is fed from a 0.4kV, 1000kVA diesel generator via a separate UPS (uninterruptable power supply) system. All complicated switchgear systems are managed by PLC (programmable logic controller). The power management system has different 50 scenarios for operation. If there is a power failure, these scenarios are run and the energy system continues to operate reliably. All floors are serviced from two lighting, one mains and one UPS distribution panel, located in the risers on the corners of each block.

Lighting

On all office floors, lighting fixtures have dark light, nine-cell parabolic reflectors louvred with two 11W compact fluorescent lamps. This lighting design elminates glare and reflection on VDUs as far as possible, and complies with *CIBSE Lighting Guide LG3, Cat2*. Compact fluorescent lamps were chosen for their ease of maintenance and low running cost. Lighting levels in the office areas are an average of 5400lux.

In the office areas, lighting fixtures are monitored by a computerised lighting control system. Each fixture is controlled separately by measuring exterior lighting levels with daylight sensors, thus providing maximum energy efficiency. This system has a 'phone switching system', meaning that areas can be switched on and off by code-dialling from the office phones.

Presence detectors are situated in the cellular offices, with occupant control provided in the form of time control programme increase energy savings. Fluorescent lamp life can be monitored easily from the system computer, as can inventory control for the lamps. That system can switch on and off UPS-fed emergency luminaires except for the uncontrolled emergency luminaires; in the event of a fire the alarm signal lighting control system switches on the all-emergency luminaires. All the control modules of the lighting control system located in the floor void are in corridors for easy access. Two lighting distribution panels per 100m^2 of floor, serving half of the floor, are located in two riser cabinets.

For external lighting, pole-top, bollard, wall-recessed and walk-over ground floodlights and impact-resistant wall luminaires have been used. For internal streets and tower lighting, 150W, 250W, and 400W floodlighting uplighters and halogen downlighting have been used. Photo-cell and time relay are used to control all such luminaires. All emergency lighting and fire alarm components are fed via low smoke halogen-free cables from UPS.

Water supply

In the Mediterranean climatic conditions prevailing in the Gebze region, very little rain falls during the summer months. In addition to the supply from the Municipal Water Authority, supplementary water for the Centre is obtained from three deep wells that have been drilled on the site. 300m^3 of water is obtained every day, which is filtered and disinfected at the water purification unit at the Energy Centre, and stored (in accordance with Turkish and EC regulations) for consumption and fire-control. Using the Municipal Water Authority supply's for irrigation is not favoured as it is a 'non-essential' use of water (it is not, however, prohibited). The Centre is surrounded by a landscaped park of about 190 000m^2 with some 6000 indigenous trees newly planted, transforming it into a recreational are with jogging trails, sporting, and resting areas. The park requires irrigation in excess of 4 litres / day / m^2 from April through September.

Wastewater from toilets and kitchen is collected at two pumping stations in the basement plantrooms and conveyed to the wastewater treatment plant to the east of the Centre. The treatment process comprises coarse screening, followed by batch system biological treatment, (medium bubble type), operating at the extended aeration level to produce a minimum quantity of stabilised waste sludge. Biological treatment is followed by advanced treatment with rapid sand filtration and disinfection, using a sodium hypochlorite injection to produce a 95% treated effluent with 10mg/l BoD5 and 10mg/l SS (higher than the Turkish and EU discharge standards and suitable for irrigation).

The treated effluent is stored to be used entirely for irrigation, via an irrigation pumping station and distribution network. This system uses a 'drip and seepage' method, with zoned electronic timer controls, thus minimising evaporation losses and maximising ground infiltration. This use of treated wastewater for irrigation is not only vital for the trees and plants on site, it also enhances the 'green' features of the Operations Centre Complex by achieving zero effluent discharge.

Conclusion: *from 'banking factory' to 'Information Age Banking Base'*

At the project's inception, the Operations Centre was conceived by the client as an efficient and functional, but rather utilitarian and highly cost-effective facility. The completed project is a functional yet sophisticated design, benefiting from high-quality engineering and effective project management. The best contractors have been used, with very reasonably costed materials and equipment, producing a high quality and prestigious facility.

YKB intends to use the standards and many of the details from this project for their other development projects including their new headquarters facilities. Due to the reasons described above, Yapı Kredi Bank decided that the original name 'Operations Centre Complex' was not doing justice to the facility and changed the name to 'Information Age Banking Base'.

Working conditions: a summary

Although some distance from Istanbul, the Centre provides an exceptionally pleasant working environment, with features including:

- *ample space for car parking (a major problem in the city centre)*
- *flexible office floors, providing occupants with freedom for space planning (a typical office floor will accommodate up to 160 people)*
- *office furniture selected for maximum comfort*
- *space efficiency and flexibility of office floors enhanced by the circulation stairs, lifts, and toilets being located in the inner streets. The ratio of net / gross area is increased up to 98.54% for the blocks. This integrated structure also helps people socialise when they are having breaks in the street cafes and courtyards.*
- *air-conditioning to provide high quality air, and allowing individuals to control their immediate environment*
- *lighting fixtures with dark light parabolic louvres to prevent glare on VDU screens. Because office space is open plan, it proved more practical to have the lighting control systems activated by signals from telephones on work-stations. Again, occupants have control over their immediate environment.*

16.
The cafeteria, the most colourful place in the Complex.

17.
Revival of Iznik ceramic tiles after 460 years, as installed in the cafeteria.

Afterword

On 12 January 1998, YKB asked Arup MMLS to do a preliminary survey and budget cost estimating for Phase 3 of the 'Information Age Banking Base' consisting of three additional blocks of about 10 000m^2 floor area, incorporating expansions for the energy centre, cafeteria, archive and storage space additional office for 700 staff.

An invitation for negotiation for the design, project management and supervision services is expected any time, to complete the project before the end of 1999.

> *'The Operations Centre Complex undertakes an enormous mission in transforming the efficiency of our Bank to an extraordinary level':*
>
> Burhan Karaçam,
> President of Yapı Kredi Bank (from an interview in *Hürriyet* newspaper, 21 November 1997)

18.
Glazed end wall to internal street.

> *'As I approached the Complex, I could see as an engineer that this was a masterpiece of architecture and engineering':*
>
> Süleyman Demirel,
> President of the Republic of Turkey
> (From his address at the opening ceremony)

Credits

Client:
Yapı ve Kredi Bankası AS
Engineering design, project management and supervision:
Arup Mühendislik ve Müsavirlik Ltd.Sti., Istanbul (Prime Agent) Ercan Agar, Ayhan C Akgün, Tufan Aksoy, Esref Alemdaroglu, Selim Alev, Hüsamettin Alper, A Hamdi Ataoglu, Clive Atkinson, Simon Barden, Simon Brimble, Phillip Ellis, Batuhan Ergünes, Brian Forster, Anne-Sophie Grandguillaume, Hayati Gurbuz, John Haddon, Andrew Hall, John Hopkinson, Ray Ingles, Serdar Karasahanoglu, Tayfun Konur, Nazmi Kuru, Geoff Lavender, Martin Long, Tony Marriott, John McKenna, Chris Murgatroyd, Simon Murray, Neil Noble, Alan Ogden, Mehmet Özaltınok, Günok Özker, Richard Phillips, Colin Pearce, Caroline Ray, Jim Read, Winston Riby-Williams, Vahap Samanlı, Noyan Sancar, Rob Saunders, Bill Southwood, Füsun Sümer, Richard Terry, Baran Tuzlacı, Harika Uyanık, Bob Venning, Elliot Wishlade.
Architect:
John McAslan & Partners
Associate architect:
Metex Design Group, Istanbul
Space planning & office furniture:
DEGW International Consulting Ltd
Interior design:
Tabanlıoglu Architects, Istanbul
Landscape advisor:
Peter Walker, San Francisco
Electrical engineering advisor:
Dr.Turgut Tüfekçi, Istanbul
Mechanical engineering advisor:
Atakar Ltd, Istanbul
Security:
Videf Security Management Ltd, Staffordshire
Catering:
Deneyim Ltd, Istanbul
Main contractor:
Baytur Construction & Contracting, Inc, Istanbul

Sub-contractors
Mechanical systems:
Isısan AS, Istanbul
Electrical systems:
AEG TAS, Istanbul
Aluminium cladding:
Çuhadaroglu AS, Istanbul
Fitout:
Proarch Ltd., Istanbul
Fabric roof membrane:
Koch-Hightex GmbH, Germany
Street roof structure:
Temsan AS, Ankara
Stone cladding:
Interstone AS, Istanbul
Landscaping:
Gardenia Ltd, Istanbul
Wastewater treatment plant:
Mass Ltd, Istanbul
Security:
Odeonist Ltd, Istanbul
Lifts:
Schindler Türkeli, Ltd, Istanbul
Building management systems:
Honeywell AS, Istanbul
Communications & data cabling:
Ericsson Telekomünikasyon AS Istanbul
Raised access flooring:
Akpınar Ltd, Ankara
Coffer infill panels:
Kabel AS - (Gema), Istanbul
Catering equipment:
Electrolux AS, Istanbul
UPS:
Remivac Ltd, Istanbul
Diesel generators:
Çukurova TAS, Istanbul
Conference equipment:
Metan Ltd.(Senneiser), Istanbul
Energy metering:
Maks AS, Istanbul
Office furniture:
Nova Yapı Ltd (Ahrend), Istanbul
Office chairs:
BMS Ltd (Herman Miller), Istanbul
Carpeting:
Akpınar (Esco), Istanbul
Illustrations:
1, 4, 5, 7, 11, 12, 13, 15, 18: Peter Cook
2: Yapı ve Kredi Bankası AS
3, 6, 8: Martin Hall
9, 10: Ray Ingles
14: Jonathon Carver
16, 17: Noyan Sancar

Byzantine Fresco Chapel Museum, Houston, Texas

Ignacio Barandiaran
Varughese Cherian
Ray Quinn
Andy Sedgwick


1.


2.


3.

Introduction

In 1990 the Menil Foundation commissioned a building in Houston to house two Byzantine frescoes: a dome and an apse. During political turmoil they had been stolen in fragments from a small 13th century chapel at Lysi, Cyprus; backed by their owner, the Church of Cyprus, the Foundation ransomed the fragments and undertook to restore them. This was done in the London workshop of Laurence Morocco starting in 1984; the late Peter Rice helped design the backup shell to support and handle them. Mrs Dominique de Menil, the Foundation President, wanted to exhibit publicly the restored frescoes, now on long-term loan to Houston, and - more importantly - restore their original religious function as sacred art. The new building, in a residential part of Houston near the Menil Collection, would thus be both museum and consecrated Greek Orthodox Chapel. The architect was François de Menil of New York, and in 1991 Arups in New York were invited to join the design team for all stages of the project.

1 above.
The original chapel at Lysi, Cyprus.

2 above centre.
The dome fragments were pieced together using computer graphics to find the original geometric form, shown here prior to restoration of the plaster and pigments.

3 top right.
The dome fresco restored and installed in the Glass Chapel: the back-up shell is a GRP/foam sandwich with embedded ribs for hoisting and handling without damage.

4 right.
The building's austerity helps to focus attention on the frescoes within.

Design concept

Menil conceived the building as a 'reliquary container' evoking the original Lysi Chapel, with a demanding set of functional and aesthetic requirements:

- It was to contain a 'Glass Chapel', an abstract spatial representation of the original.
- The architecture had to focus attention on the frescoes through carefully chosen materials, textures, colours, and craft.
- The structural system to suspend the glass panels had to harmonise with and reinforce this vision, necessitating thorough investigation of the technologies of curving, sand blasting, and supporting thick glass panels.
- An environment meeting the strictest curatorial standards of temperature, humidity, air quality, and annual illumination exposure was vital to the frescoes' preservation.
- The lighting, natural and artificial, was to be a key element in creating a contemplative atmosphere.

Solutions were developed through close collaboration between the architect and Arups' multi-disciplinary team.


4.

Structure

The project had two distinct design elements:

- the 4000ft^2 (370m^2) main building, comprising the reliquary container, ancillary areas like the entrance lobby and sacristy, and support spaces including bathrooms, basement and equipment rooms
- the Glass Chapel, including the supporting armature for the frescoes.

The main structure is mostly architectural load-bearing concrete masonry and in situ concrete exposed on interior surfaces. The exterior is clad with precast concrete panels, field stone facing, and lead-coated metal panels. The in situ concrete had to achieve surface, joint, and colour uniformity, and a value engineering exercise with the contractor established the formwork materials and joining methods, arriving at a more economical solution in tune with local practice. By investigating available techniques and using mock-ups, finishes of a high quality were achieved to the architect's and owner's satisfaction.

The main room, 30ft wide, 46ft long, and 29ft high (9.1m x 14m x 8.8m), contains the Glass Chapel. It has double walls, the outer cast in situ concrete and the inner of 0.375in (9.5mm) steel plate; the roof is structural steel with a slab on deck. The outer concrete 'box' is open to the sky, while the inner steel 'box', 2ft (600mm) smaller in plan to fit inside, has its bottom open to the ground. The inner box is suspended from steel columns about 8ft (2.44m) above ground, creating a continuous perimeter skylight; sunlight penetrates the building down the 2ft wide, 20ft (6.1m) high gap between the two 'boxes'. Arups developed a system to stiffen and suspend the steel plate walls, including framing details.

The Glass Chapel itself had to follow the form of a classical Byzantine church, accurately fitting the scale and dimensions of the restored frescoes. The dome is c9ft (2.74m) across. The glass panels had to seem to float, the glow from hidden light sources not disturbed by the presence of structure. The frame had to recede at first glance, yet have a tactile quality derived from its craft and precision.

Initially, tempered glass with load-bearing fixings was considered, giving the glass a primary structural role, but surface distortions for curved panels were found to be excessive, making thicker laminated panels difficult to achieve and unacceptable in appearance. Also, the spatial composition of distinct glass panels was intended to recall the frescoes' recent history, their fragmentation and restoration, so an architectural expression of semi-concealed connections was unsuitable. The final solution involved steel U-clips mechanically fastened to T-connectors shop-welded to the frame. The laminated panels are 1.5in (36mm) thick, made of two sheets of annealed Starfire water-white glass. They have a sand-blast finish sealed with Stand-Off TMP, including all edges which are also arrissed. The clips are lined with custom-machined Delrin bearings, designed with a snug fit so they cannot slip out, but shaped to allow a small amount of rocking of the glass inside to accommodate any rotational misalignment. Although these bearings had a higher up-front cost, there were savings in the labour required for a silicone-sealed alternative, and the result is consistent and unobtrusive. This simple but precisely engineered technique to support the glass, and the hierarchy between structural frame and infill panels, was crucial in executing the project on time and budget while achieving the architectural objectives.

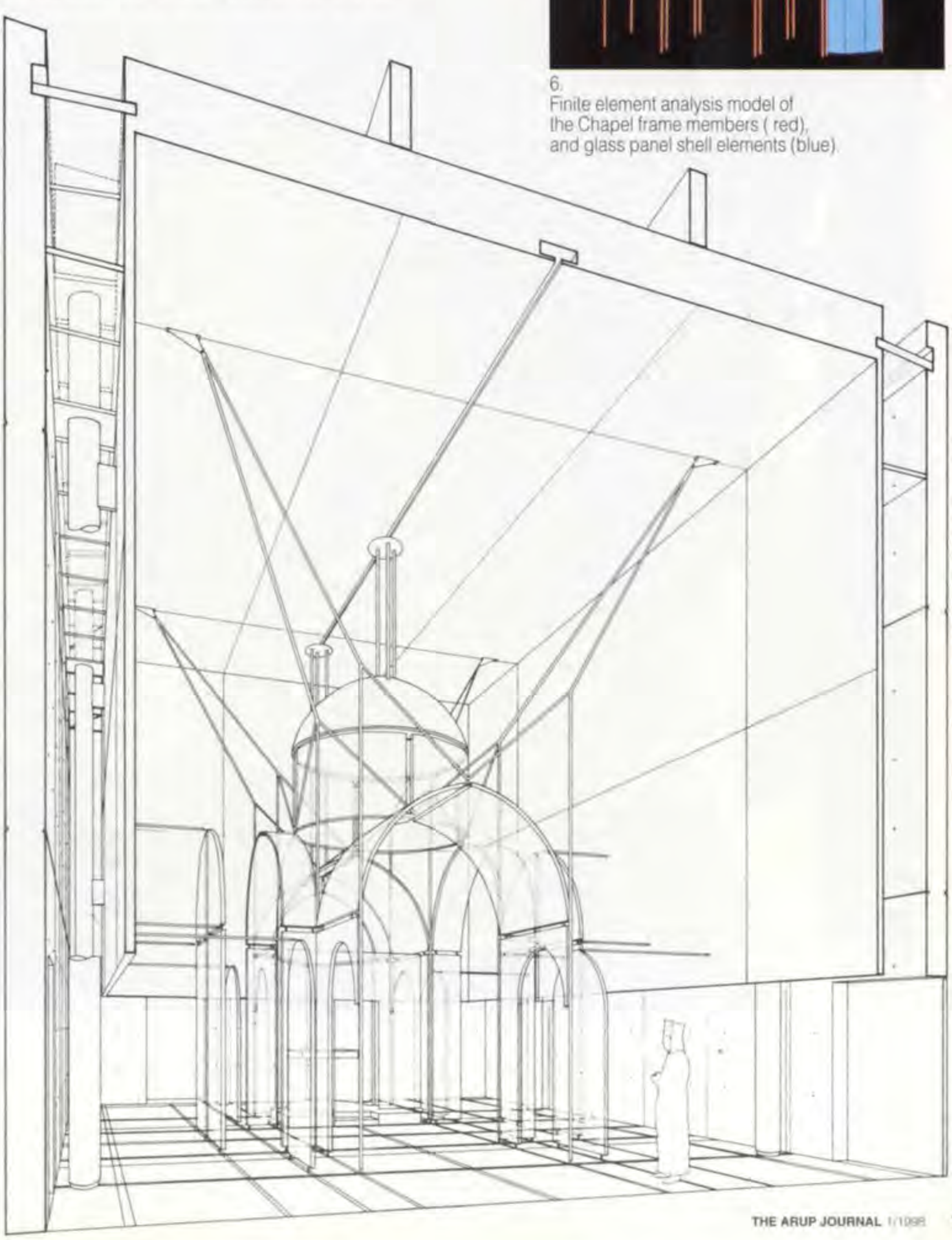
The supporting structure was conceived as a literal inversion of traditional load-bearing masonry in compression: suspending the steel rod framework from the roof structure to carry the gravity loads, and anchoring it to the floor to give lateral stability. From this tensile network, the glass panels were to be hung, framed by U-clips on all four sides. The dome and the apse were to be hung from the roof, independently from the Glass Chapel.

The basic structural unit is a plane frame, c19ft high by 9ft wide (5.8m x 2.74m), stable vertically and in-plane laterally when anchored top and bottom. Four such frames around the dome, plus one at the apse and another at the front, define the Chapel. Eight inclined hangers were used to suspend the frames from the roof, whilst two additional sub-frames define the barrel directly below the dome and the back of the apse around the altar. In addition, two free-standing plane frames define detached glass walls on the short axis of the Chapel. Initial studies were made of the behaviour of the basic frame under self-weight plus a lateral and gravity superimposed load of 5lb/ft^2 (24.4kg/m^2) from all glass surfaces, in addition to point loads representing the effects of persons hanging or pulling on specific frame members. To keep all member sizes to an absolute minimum, the frame is prestressed eliminating compression. Member diameters varied from 0.375in (9.5mm) to 1.065in (27mm), the latter being pipes with 0.25in (6mm) thick walls. Rods were ASTM A-29 Gr. 8620 and pipes were A-106 Gr. B, both weldable materials. The steel frame was given a matt black oxidised finish. Arup Research & Development in London were involved in selecting materials and specifying welding and testing procedures.

To demonstrate the lateral and vertical stability of the entire frame, the basic plane frames and the barrel and apse frames were assembled in a full three-dimensional analysis. The frames' interaction with the glass panels was studied using finite-element shell elements, given that only bearing and out-of-plane restraints are possible at the U-clip connections. This model was used to study deformations for the panel installation sequence.

Details were developed to give as smooth and uniform an appearance as possible for welded and mechanical connections. The more precise weld obtainable with GTAW (TIG) electrodes, although slower, was important, given the small size and intricate nature of the welded joints. The connection of the hangers to the roof structure incorporated custom turnbuckles for ease of installation and threaded connections with Belleville springs.

An important aspect of constructing the Glass Chapel was to match tolerances for glass and steel fabrication and erection, and Arup Façade Engineering's involvement in discussions with contractors was crucial to ensure that the finished product met the high standards required. The principal task was to review at the glass fabricator's plant all aspects of cutting, curving, laminating, trimming, and polishing the panels, a detailed specification being drawn up and agreed to by the fabricator. Other topics thoroughly discussed included the range of movement allowed at each U-clip relative to the as-fabricated glass tolerances, for the curved panels in particular, as well as preferred ways of handling and installing the glass.

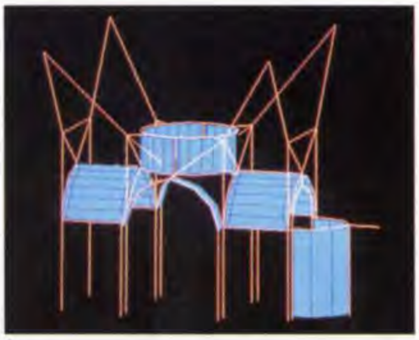


5.
Architect's perspective of original concept, showing the box-within-a-box concept for the 'reliquary box' with the Glass Chapel strung between roof and floor.

Mechanical systems

These had to satisfy two main design criteria: for an environment conducive to long-term preservation of the frescoes, and comfortable conditions for building occupants. The latter is particularly significant as, in the building's function as a church, the congregation may be seated for lengthy periods.

The prime need was to protect the Chapel area itself. The entrance lobby and the sacristy form buffer zones, each air-conditioned independently by customised packaged rooftop heat pump units. In addition, the Chapel was positively pressurised to further reduce infiltration. Other elements like the baptistry and main equipment rooms also surround and buffer the Chapel space, which is further protected from internal and external thermal load changes by the heavy precast concrete walls, the high thermal mass of the exposed interior concrete, the indirect daylighting limiting the thermal impact of solar radiation entering the building, the light exterior colour, and the low reflectivity of the steel inner walls. Detailed modelling and analysis of all these kept mechanical systems to a minimum.



6.
Finite element analysis model of the Chapel frame members (red), and glass panel shell elements (blue).

7.
Sample of laminated glass panel with machined steel U-clip and Delrin gasket.

The Chapel itself is air-conditioned using an all-air, single zone system with the air-handling unit (AHU) at basement level. Conditioned supply air is delivered by the AHU to the sealed basement below the Chapel; this acts as a pressurised air distribution plenum with air entering the Chapel above via narrow slots cast into the concrete floor structure, some around the perimeter directly below the inner steel wall, the others in a group immediately under the Chapel's glass panels, tracing its outline to the floor. The perimeter slot allows air to be delivered to parts of the space immediately affected by the skylight heat gains and losses. Displacement air distribution techniques deliver air to within the Chapel itself and to its surroundings, ensuring uniform air conditions on all sides of the frescoes. Air is extracted via a high level architectural opening just above the frescoes. Temperature and humidity sensors in this return air control the supply air conditions, ensuring they are correct at the frescoes. The system uses a high air change rate for good air filtration and the resulting relatively high supply air temperatures ensure occupant comfort. Arup Acoustics' Los Angeles office reviewed fully all mechanical system noise control measures, to ensure the NC30 noise criterion was met by the final design. Initial schemes for this system included high degrees of component redundancy but the final design did not include these redundant components due to the additional costs. Before the frescoes were installed, the system was load tested to ensure safe and proper functioning.

Lighting

Natural light enters through slots between the concrete outer shell and the inner steel liner, and reaches the perimeter walls and floor both directly and by inter-reflection within each slot. On clear days direct sunlight falls on the concrete or the steel and is reflected down into the Chapel below. The fresco pigments can be damaged by excessive light, so dimensions and surface finishes in the natural lighting slots were designed to ensure that inter-reflected daylight levels on the frescoes are less than 20lux under most lighting conditions. Direct sun aligns with the slots for up to 20 minutes each day, at which times daylight levels on the frescoes remain below 60lux.

Electrical systems

The electrical supply to the building was rather unusual since the incoming service was provided by a three-phase, 240V, delta system with a grounded centre tap only on one phase.

This particular transformer configuration provides 120V only on the phase with the centre tap, 240V between phases, and 208V between the untapped phase and ground. Balancing the electrical load across all three phases with such a system was quite a challenge.

Several tungsten halogen fixtures on the supporting structural frame, their low voltage wiring threaded inside the steel tubes, light the Glass Chapel. Fluorescent lighting fixtures in the basement plenum directly below the ventilation slots provide a glow to the lower portion of the glass panels. In evenings and on cloudy days the daylight effect is provided by fluorescent strip lighting between the concrete outer shell and the inner steel liner.

Smoke sampling similar to the Vesda system provided the fire detection and alarm system for the Chapel; beam detectors proved ineffective due to the number of obstructions from the structural framework. Normal smoke detectors were provided in all other areas.

8.
The completed Glass Chapel.

9.
Construction of the concrete walls and steel structure to support inner steel walls and roof. The roof slab edge is pulled 2ft away from the walls forming the continuous perimeter skylight.

Conclusion

Though delayed significantly between design and construction because of financing via fund raisers, the project was successfully built within construction programme and budget because the design team committed itself to rationally defining and achieving its goals. Also, the 'partnering' approach with an excellent and equally committed contractor helped bridge the gap between design and construction. Excavation began in October 1995, and work on the building continued to September 1996. The Glass Chapel was erected in two months, the frescoes installed in January 1997, and the Chapel Museum inaugurated on 8 February 1997. The owner was extremely pleased with the result.

Credits

Owner:
The Menil Foundation

Architect:
François de Menil

Engineers:
Ove Arup & Partners
Ignacio Barandiaran, Daniel Brodkin,
Guy Nordenson (structural)
Andy Sedgwick (lighting)
Richard Bussell (acoustics)
Tom Barker, Varughese Cherian, Igor Kitaygorodsky,
Raymond Quinn, Mahadev Rahman, David Richards,
Carleddy Sanon, Da Teng (building services)
Nicos Peonides (communications)
Simon Cardwell, Graham Gedge (materials)
Graham Dodd (façades)
Lou Gargiulo, John Miller (CAD operators)

Civil engineers:
Couburn Linseisen & Rattcliff

Landscape architect:
Daniel Stewart

Glass Chapel lighting design:
Fisher Marantz Renfro Stone

General contractor:
W.S. Bellows Construction Corporation

Glass Chapel frame fabricators:
Tripyramid Structures
Atlas Metal Products

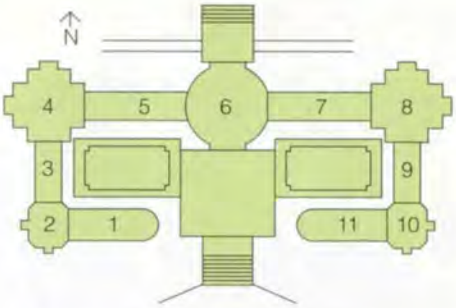
Glass fabricators:
D'Luback Corporation

Glass and metal finishing:
Robert Pringle

Illustrations:
1, 2, 5: François de Menil
3, 4, 8: Paul Warchol Photography
6, 7, 9: Ignacio Barandiaran

Enid A Haupt Conservatory, New York

Liam O'Hanlon



1. Layout of Enid Haupt Conservatory.

History

The largest conservatory in the USA was constructed in two phases from 1898 to 1901. The design was by Lord & Burnham, the premier greenhouse company in the States at the time, and called for the construction of 11 houses totalling 42 000ft^2 (3900m^2) of plant area. The Conservatory was one of the company's crowning achievements, as evidenced by its extensive use in their brochures for decades after completion.

While every care was taken in the original design and construction to ensure it was built to the highest standards using the latest technology, internal and external environmental stresses rapidly proved overwhelming. By 1921 the entire roof of the Palm House (House 6) was replaced, and in the 1930s, deterioration required a major renovation. Arups had access to that renovation's wonderfully detailed field measured drawings, which formed the basis of our own drawings.

In the 1950s another repair programme - of major importance to Arups' later work - was undertaken, including replacement of the grand cast iron entrances to House 6 with exceedingly ugly masonry boxes. This was an unfortunate loss of the most elaborately detailed portion of the Conservatory. The final major repair campaign came in the mid-1970s following designation of the Conservatory as a New York City Landmark and renaming for its major benefactor, Enid A Haupt. The Landmark designation helped save the ailing facility from demolition and replacement.

Original design and modifications

The inspiration was the Palm House at the Royal Botanic Gardens, Kew, seen on a honeymoon visit in 1888 by Nathaniel Britton, Director-in-Chief of the New York Botanical Garden. Although the Palm House had been built in 1847, little had changed in greenhouse technology in the intervening decades. The one structural advance available for the New York Conservatory was steel for its superstructure. With its greater strength and fabrication ease, steel gave greenhouse designers new freedom to lighten further their structures visually and resist decay.

The final design was a C-shaped structure: 11 individual greenhouses arranged symmetrically on either side of the central, 20-sided, double-domed House 6. The long side of the C measures c500ft (152m), whilst House 6 is some 100ft (30m) in diameter and 90ft (27m) high. On either side of it, in succession, are a low curvilinear house, a double-domed cruciform house, another low curvilinear house, a small square double-domed house and finally - completing the C-shape - a low curvilinear house. All are on rubble stone foundations with stone-faced brick knee walls above grade.

Except for House 6, the superstructures rested on cast iron sills simply mortared to the tops of the masonry knee walls. The basic structure was 0.5in (12.7mm) steel plate rafters curved to match the curvilinear roof profiles. The rafters were set on 8ft 4in (2.54m) centres, connected at their tops to continuous ridge plates of similar dimension. In the long houses the rafters were tied together about one-third of the way down from the ridge by 0.875in (22.2mm) tie rods with turnbuckles. Between the steel rafters intermediate support of the glazing bars was provided by steel angle purlins running perpendicular to the rafters. Hips, valleys, ring beams, and compression beams were also in steel plate. No lateral bracing was installed in any of the buildings. In Houses 4 and 8 - the large corner pavilions - intermediate roof support was from 6in (152mm) diameter round wrought iron columns braced at their tops by double angle knee braces. The rafters were held to the cast iron sills by lug bolts and cast iron clip angles. Tying the buildings together at eaves height were cast iron gutters c12in wide and 8in high (305mm x 203mm), spliced together at each rafter with large cast iron brackets finished with decorative cover plates. All connectors of rafter to rafter, purlin to rafter, glazing bar to purlin, etc, were tough grey cast iron clip angles and shoes. All bolts were steel or wrought iron.

Because of its size, House 6 was framed very differently. The lower dome was supported on 20 steel lattice truss columns about 2ft (610mm) deep, curved to match the roof profile. The lattice columns are equally spaced about the circumference of the dome, forming a 20-sided faceted base. These lattice columns rise to a steel compression girder on which rests the upper dome, framed with plate rafters similar to the other houses. Because of the large distances between the lattice columns, the purlins for the lower dome were light lattice beams about 16in (406mm) deep. The lattice columns rest on large stone foundation caps which rest in turn on brick footings below. The impressive façade at the base of House 6 rests on the masonry knee walls below, and consists of cast iron fluted columns with highly decorative capitals supporting cast iron box beams and gutters above. Although the original specifications called for the façade to be tied back to the steel superstructure, no evidence was found that it had ever been done.

The Houses were glazed with 0.125in (3.2mm) annealed glass, curved to match the roof profiles and installed like shingles with a 0.375in (9.5mm) lap. The glass was set in special greenhouse putty and secured to the wood glazing bars with wedge-shaped zinc nails. The glass was supported on clear air dried cypress glazing bars approximately 0.938in x 1.875in (23.8mm x 47.6mm), and on cypress hips and valleys fabricated to conform to the complex curves formed by the intersections of ellipses of different radii. The glazing bars were supported intermediately by the steel angle purlins and connected to them with cast iron clips.

▶

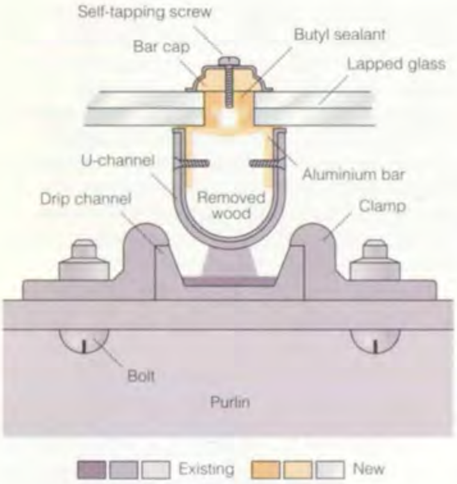
2. View looking southeast prior to restoration.

3.
Mock-up work under way prior to issuing of construction documents.

4 below.
Typical deterioration of wood valleys.

To prevent corrosion or deterioration and to minimise maintenance costs, all steel and iron members were washed clean with lye (a caustic liquid made by leaching wood ash), pickled with acid, and again washed to remove the acid before painting. The ironwork was warmed slightly and painted with red oxide lead before delivery and then again after being set. The woodwork was prepared by dipping in a mix of iron oxide and linseed oil before shipment. Once installed and before any glazing went on, the entire structure, iron and wood, was painted with one coat of pure white lead and linseed oil, inside and out. Another coating was applied after glazing.

When originally built, the Conservatory had cypress glazing bars supported by the steel purlins, but within 20 years the entire wood roof glazing in House 6 needed replacement. In the 1930s renovation the structural function of the wood glazing bars was relieved and they were shaved down and set in galvanised steel U-shaped bars, which now gave structural support for the roof glazing. The wood inserts were still used for setting glass in the traditional manner with putty and zinc glazing points. In the 1950s renovation, aluminum bar caps were installed on all the wood glazing bars, which eliminated the costly requirement of painting the 6.5 miles (10.4km) of glazing bars every few years. The 1970s renovation saw the replacement of about 10% of the cypress glazing bars with redwood, and the roof was completely reglazed, again using the wood inserts and the aluminum bar caps. Rather than setting the glass in putty it was now set in open cell foam tape. But this time the wedge-shaped glazing points were not used and the glass was now secured by the upper corners of the overlapping bar caps.



5. Typical glazing bar

6.
Cast aluminum entry to House 6 after restoration.

7.
House 6, after restoration.

Arups' work

Glazing system

The team was commissioned in 1990 to undertake a renovation intended as the most thoroughgoing since the 1930s. At the outset the project budget was established at $11.2M - recognised early on as low, and necessarily limiting the project scope to addressing fundamental problems only.

The architect, Beyer Blinder Belle of New York, made an extensive review of the archives at the Garden and elsewhere, and assembled a comprehensive Historic Research Report which proved invaluable in helping Arups understand the building and diagnose chronic problems. Archive material included original drawings and specifications and even the punchlist issued to the contractor prior to accepting the work. As well as this documentary research, Arups and the architect visited conservatories in the USA and Europe to gather information on common greenhouse problems, and examine successful restorations. Early technical assistance was sought from Arup Research & Development in London, who were instrumental in getting the work off on the right foot and provided valuable input as it progressed.

Following the archival research Arups extensively interviewed the Garden maintenance staff. Replacing 200-300 panes of glass each year was an enormous maintenance burden sapping the Conservatory's limited resources, and its solution quickly became top priority. Although the building envelope normally falls within the architect's scope of work, Arups' expertise in materials behaviour and the complex interplay of glass, putty, wood, iron and steel led the team to take on the task of diagnosing the roof system deficiencies and designing the repairs.

Materials research, staff and manufacturer interviews, monitoring the structure, investigating ongoing maintenance techniques and materials, and visits to other conservatories all led to realisation that the glass slipping and cracking was not due to wind stresses or seasonal or thermal movements. Failures occurred on all houses in random patterns and weather conditions, and only after months of field and office research did the diagnosis become clear.

Arups determined that the chronic glazing failures were caused by the bar caps coming loose due to natural movement of the building under wind loads and the poor screw holding capacity of the soft-wood glazing bars. The curvilinear geometry of the roof exacerbated the problem greatly. Other conservatories with the same glazing system but flat roof profiles reported none of these failure problems.

The first possible solution was to redesign the existing system while still using the wood bar insert. Arups' investigation indicated, however, that the bars would have to be replaced if the new system was to satisfy future maintenance requirements for a standard width glass throughout. This was primarily due to the slight variability of the U-bar spacing and the inability of the wood inserts to provide sufficient bite to the glass for proper sealing. But as the possible wood option was explored problems of availability and sustainability soon arose. The first growth swamp cypress used originally was excellent for greenhouse use, clearly shown by the comparatively good condition of the 60-year-old cypress relative to the already deteriorated 1970s' redwood replacement. But sources for first growth cypress were unreliable and did not meet the Garden's criteria for sustainable harvesting of timber. Other decay-resistant woods were researched but again, issues of sustainability, quality, and availability arose. In the end the team was unable to develop a glazing system which still used wood, would be better than any alternative, and could be maintained with the same materials. Also, the existing design had been radically modified from the original and the wood remnants had become troublesome remnants. A design was thus developed entirely with aluminum members. The wood bars were replaced with aluminum inserts, invisible in the final work but giving the required bite to the glass in every instance. Aluminum replacements for the visible valleys and hips were extruded to match the profiles of the original wood members.

The other important part of the system redesign was the material for setting the glass. Again after extensive research, Arups settled on butyl, plus EPDM gaskets on the feet of the bar caps to reduce glass-to-metal contact. But to hold the gaskets the bar caps would now have to be extruded and necessarily heavier and stiffer than the existing light gauge pressed aluminum caps.

Since the design was new to greenhouses the system had to mocked up before finalising the bid documents. This was done in a geometrically complex area of the building so that virtually all the new shapes and designs could be tried out. For maximum benefit, various glazing sealants - butyl rope of different thickness, butyl sealant, rubber putty, and silicone - were included. The mockup subtly changed virtually every aspect of the design, but given the component nature and size of a building like this little changes are repeated many times and thus have a profound impact on ultimate success or failure. Virtually every piece was reconfigured to carry water better, to insure adequate bite on the glass, or to support the glass better. The final design used 0.25in (6.5mm) butyl rope with an 0.125in (3.2mm) core and a gunnable butyl top seal. The rubber core of the setting bed ensured that glass would always be resting on sealant rather than metal. Where exposed in the final installation, silicone top sealant was specified because of its greater resistance to UV degradation. Using butyl as the general sealant was challenged later by the contractors but Arups judged, and the owner concurred, that butyl would simplify future maintenance. Structural assessment of the properties of silicone and butyl indicated that butyl provided well in excess of the required flexibility, adhesion, and strength, and concerns about UV degradation of butyl were obviated since it was protected by the bar caps. Prior to installation, tests verified that the butyl and silicone were compatible at junctions and would perform as required.

Foundations, superstructure and cast iron

As well as the glazing system, time was spent on more traditional structural issues such as localised underpinning, rebuilding masonry walls and roofs, and most importantly restoration of deteriorated, cracked, and otherwise distressed iron and steel members.

Because of limited funds for partial investigatory removals and the physical difficulty of examining the building interior with plantings in place, only limited areas of the structure were investigated prior to start of construction. Typical distress-prone areas were accessed and taken apart from outside to understand the construction better and assess visible signs of deterioration. In the end, difficulty of access left many areas unexamined and the condition unknown.

Structural investigations uncovered various systemic problems with cast iron elements and isolated areas of corroding steel, but generally the structure was sound. The greatest adventure during the investigation occurred the day the top of House 6 was examined from a bucket suspended by the hoisting cable of a very large crane. This arrived and was set up just in time to coincide with wind speeds of 50-70mph! The ride was memorable but the inspection understandably brief. Luckily, the amount of corrosion and repairs required in this large house decreased dramatically with height.

There was much discussion and research on materials to replace deteriorated iron and steel, but finally it was decided to replace in kind for technical and aesthetic reasons. Although new cast iron elements were more costly than cast aluminum, the latter's crisp detail seemed out of place beside the softer texture of the cast iron, and the owner agreed. Cast iron also has exceptional corrosion resistance when exposed and properly detailed, and a greater ability to hold field-applied paint. Additionally, by replacing metals in kind problems associated with detailing for bimetallic corrosion were minimised.

Construction

Contracts were let in early 1993 and construction began in April, just after the United States Environmental Protection Agency issued unanticipated emergency regulations for lead paint abatement. Monitoring the air in accordance with the new regulations soon brought blasting work to a halt. This delayed the project for three months while increased funds were secured, specialists researched and hired, and contractors properly trained. A new painting contractor with the proper equipment and an environmental monitoring firm were hired and the work proceeded in accordance with the new regulations.

In consequence the painting contract doubled from $1.6M to $3.3M dollars. Blasting and painting proceeded systematically through the houses by completely enclosing areas inside and out to create manageable volumes for proper filtration and air movement in the work zones. To eliminate stress on the lightly framed buildings, all enclosure scaffolding, inside and out, was self-supporting. House 6 had one of the largest free-standing scaffolds ever erected in New York City.

Because it is recyclable the paint was removed with steel shot, thus reducing hazardous waste by some 97%. Unfortunately, use of steel shot in a finely detailed building like this also results in small steel particles lodging in crevices, with rust stains on large areas of the finished work. Over time this problem has lessened dramatically, however, and is no longer obvious.

The coating system is an inorganic zinc-rich primer with an epoxy-based intermediate coat plus a top coat of polyurethane for colour stability.

Most metal corrosion problems were discovered while blasting the ironwork clean. Several times, relatively large pieces of cast iron became suddenly dislodged by the blasting. As soon as areas were blasted and primed, pieces to be repaired or replaced were identified, and repairs to steel began right away. Due to rust jacking at the joints, many cast iron gutters, connectors and clips needed replacing by matching castings of grey cast iron. Minor redesign of these details will markedly reduce these problems in the future. The galvanised purlins and U-bars were in remarkably good condition and required minimal repairs. ▶

8 below.
Interior of House 4
with plantings reinstated.

The greatest cast iron repair challenge was the 20ft (6.1m) high façade at the base of House 6. Removing the fascia panels of the large box beams forming the entablature uncovered extensive corrosion. The largest repair required shoring the structure locally and removing one of the cast iron columns to repair a large hole and a 2ft (600mm) long crack emanating from it. An arresting hole was drilled to prevent the crack from propagating, and a mechanical patch repair was made with an interior stainless steel plate insert and flush mounted bolts. The remaining surface depression was epoxy-patched and painted. All new internal connector clips and fasteners for cast iron repair were stainless steel, bimetallic corrosion between the two materials being prevented by painting the former before installing the latter.

To secure the 320ft (97.6m) circumference of the façade, internal stability was ensured by installing new stainless steel internal box-to-box connections for circumferential thermal expansion of the façade while restraining differential outward movement. No attempt was made to positively tie the interior steel and exterior cast iron structures together - the cure was judged to be worse than the illness.

While the painting, concrete, and iron work proceeded well, the roof glazing did not. The work was let to the low bidder even though they did not satisfy the construction documents' requirement that only a firm with greenhouse restoration experience should perform the work.

Regrettably, their suppliers and installers were similarly unqualified and this work proceeded with great difficulty on every front.

After much delay and anguish the Garden was forced to co-hire with the glazing contractor a greenhouse restoration contractor as construction advisor to help them understand the project and teach them how to do the work. To resolve installation quality issues the Garden hired additional staff with greenhouse experience to train the contractor's field forces and to monitor the construction continuously.

All this helped greatly and got the project back on track, but a few major technical hurdles remained. After the contracts were let, problems with the earlier roof glazing mockup installation began to appear. They could not be traced to any particular area or assembly method but several pieces of glass had cracked over time, usually after windy storms. Since it was now too late to change the bid documents, Arups relied on the requirements of those documents for an additional mockup to evaluate the design further. Through additional assessment of the pre-construction mockup and discussions with the greenhouse restoration contractor, the gasketed bar cap design was established as the likely culprit, primarily because of the greater stiffness of the new bar cap and the fact that the extrusion was manufactured and bent to exact radii while the building was slightly out of tolerance everywhere. To remedy this Arups redesigned the cap by reverting to a pressed aluminum cap and widening it slightly to ensure a positive glass stop and curving the legs slightly to soften the glass-to-metal contact point. Curving the feet also added a desirable 'spring' in the bar cap.

The result was immediately apparent: the caps went in easily and positively and could be bent slightly by hand to conform to the varying radii of the glass.

The Conservatory was opened in May 1997; since then no problems have been reported.

9.
House 6: Interior with plantings reinstated.

Credits

Clients:
New York City Department of General Services
New York Botanical Garden

Architect:
Beyer Blinder Belle

Structural engineer:
Ove Arup & Partners
Poul Beckmann, Ray Crane, Graham Gedge, Peter Leheny, Chris Murgatroyd, Liam O'Hanlon, Peter Ross

Services engineer:
Ambrosino DePinto & Schmieder

Greenhouse construction consultant:
Rough Brothers, Cincinatti

Exhibit design:
Coe Lee Robinson, New York

Project management:
New York Botanical Garden Capital Projects

Glazing contractor:
Harmon Contract WSA, Stamford, Connecticut

Painting contractor:
George Campbell Painting, Flushing, New York

Ironwork:
Post Road Iron, Greenwich, Connecticut

Illustrations:
1, 5: Nigel Whale; 2-4 Ove Arup & Partners
6: Beyer Blinder Belle; 7: Jake Rajas
8-10: Fred Charles

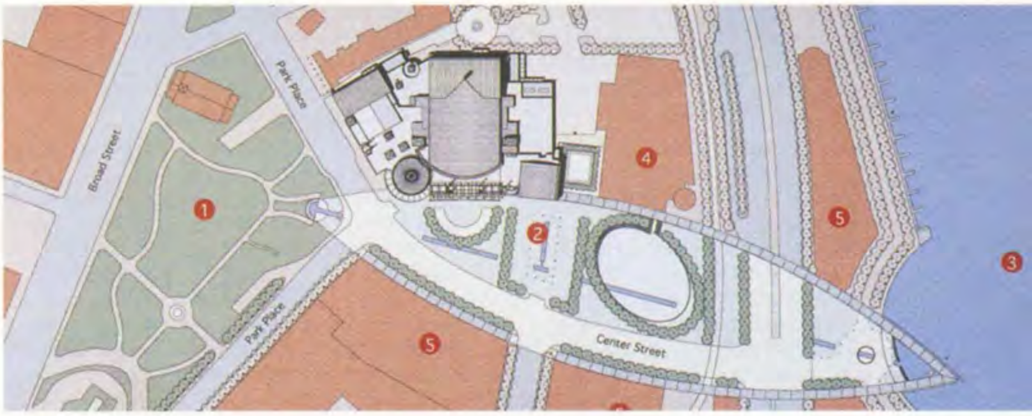
10.
View looking northwest.

New Jersey Performing Arts Center

Jacob Chan
John Gautrey
Nancy Hamilton
Alan Locke

1. NJPAC in its urban setting.

2 right:
Architect's site masterplan:
❶ Military Park,
❷ Theater Square,
❸ Passaic River,
❹, ❺ Future development.



Introduction

In the aftermath of the 1967 civil rights riots, the City of Newark, with the State of New Jersey and private developers, undertook several commercially-based revitalisation projects in its inner city area, such as the Gateway Center. These, however, were only a limited success, and inspired by a 1987 State initiative, the City - led by New Jersey Governor Bill Kean - embarked on a new program to revitalise the area by expanding its arts and cultural base. This aimed to provide a new downtown complex giving the local community not only world-class performances but also a centre for learning and recreation - and more employment to Newark's diverse population. The approach relied heavily on partnership between the State, the City and its citizens, and, most crucially, the local industrial and commercial institutions with a major business stake in revitalising Newark and its surrounding districts.

The project required a dedicated and energetic owners' team (Larry Goldman and Gail Thompson), plus an experienced and enthusiastic architect and design team, to realise the vision of this centre as the hub to a city of the new Millennium.

Barton Myers, with whom Arups worked on the Cerritos Performing Arts Center[1], was selected as architect in 1990, and he requested that Ove Arup & Partners California be employed as the project building engineers.

The brief

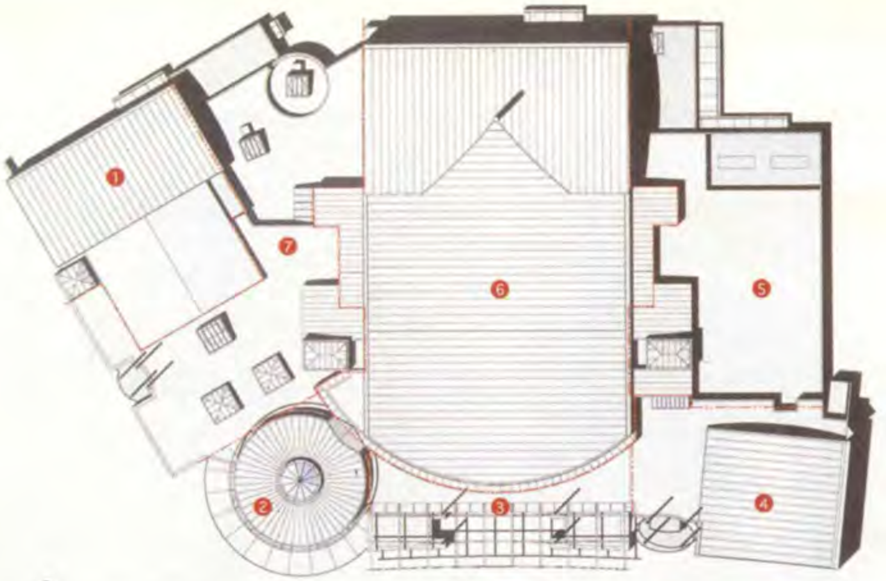
The centre was to be the cornerstone of a 12 acre (4.8ha) development covering the riverfront area and including office space, mixed-use development, and arts-related uses. The client wanted the centre to rival the best in the world, able to compete with Carnegie Hall in Manhattan 30 miles (50km) east across the Hudson, and housing a performance space for theatre, opera, and concerts as well as a smaller community playhouse. A great lobby for community functions and dining, a rehearsal room, a community room, a lounge, an administrative centre, plus the support spaces needed for a centre of this complexity, would also be provided.

For world-class performances, the main multi-purpose hall (Prudential Hall) would not only be designed to the strictest acoustic requirements (N-1), but would seek to immerse the audience in the performance by creating an intimate relationship between performer and patron. These requirements were significant challenges for a 2750-seat hall that also needed built-in flexibility to accommodate a changing ceiling profile, adjustable acoustics, and reconfiguration of the stage pit.

Architectural concept

All too often, performing arts centres tend to be large in exterior scale but focus on the interior rather than attempt to deal with context or exterior relationships. This first phase, together with future arts and commercial developments, is intended to form a new 'urban room' or 'Theater Square' - a public plaza linking Military Park, the original commons of Newark, to the Passaic River. This outdoor area was designed to serve patrons and community as both a day and night-time space. The main lobby opens into it for patrons to pass into the plaza, whilst the park-like setting with benches and trees encourages people to linger during the day. A common vocabulary of patterned brick, glass, and steel unifies the buildings whilst, like many of Barton Myers' projects, the scale, massing, and materials are compatible with the urban context, using materials found on buildings throughout the Newark area. The large steel external lobby truss mimics the great iron bridges that dot the local landscape, and the brick blends with the surrounding turn-of-the-century buildings.

Continues overleaf: ▶



3.
The main elements of New Jersey Performing Arts Center: ① Victoria Theater, ② Rotunda, ③ main lobby, ④ restaurant/banqueting/rehearsal, ⑤ kitchen/mechanical, ⑥ Prudential Hall, ⑦ dressing/administration.

Prudential Hall's fly tower was strategically placed at the back of the site to allow the lobby, donors lounge, rehearsal room, restaurant, and offices to enjoy views of downtown and the river; the carefully shaded expanses of glass allow views into and out of the building.

Both performance rooms are expressed as individual buildings which appropriately address the street each through its own lobby and façade. The more intimate scale of the smaller Victoria Theater, across from Military Park, gives way to the grand gesture of Prudential Hall and its lobby onto Theater Square. A rotunda 'hinges' the two façades. More activity spills out from the restaurant and shops, giving further energy and vitality to surrounding streets and Theater Square. A continuous arcade provides a covered promenade around them, and flags and banners further heighten the festival atmosphere.

The lobbies and rotunda form transitional areas between city and auditoria. The public pass in to purchase tickets, listen to a noon jazz concert in the lobby, or dine at tables spilling out from the café. With multiple levels, dramatic views, and other theatre-inspired elements like the box fronts, the lobbies become performance spaces in themselves - a place to see and be seen. Again, materials and colour palettes - custom carpets, Portuguese stone paving, and hand-laid tiles derived from traditional Kente cloth patterns - reflect the vibrant and diverse ethnic community of Newark.

Prudential Hall is modelled on a traditional opera house configuration, with proscenium and full stage house. The 2750 seats are arranged on a parterre and four tiers wrapped around the sidewalls, bringing the audience as close as possible to the stage and thus drawing performer and patron together. This configuration also gives the fullest possible view of the audience chamber from each seat, heightening a sense of shared public spectacle and celebration. The feeling of the patron being intimately involved is a critical issue in Barton Myers' work. The use of wood, copper, and celebratory fabrics brings a sense of warmth to the main hall.

Victoria Theater seats 500 as a venue for local dramatic and choral groups, chamber orchestras, and stage performances. The layout is derived from an English courtyard theatre with a single balcony and seating along the sidewalls. The provision of a stage house allows both touring dramatic companies and resident dramatic groups to present their work; this space can also be used for black box presentations.The stage door is celebrated with its own rotunda and actors' lounge.

All the back-of-house areas, eg dressing rooms and administrative offices, have abundant natural light, with areas for formal and informal practice throughout. All these spaces are connected internally as well as with the performance rooms and lobbies, allowing ease of control and movement between front and back-of-house operations.

The process

From the first design team meeting, the client not only set the project goals of quality, image, cost-effectiveness, and urban planning, but also successfully made each team member believe that their individual expertise was critical to the project's success. All the design and construction team members were present at each meeting and were expected to participate. The client led the early design sessions, often involving the team in long discussions on the merits of various proposals, with numerous studies into critical issues.

The engineering was seen as an integral part of the architectural design, as were the other disciplines. For example the lobby truss and the rotunda roof structures were examined and re-examined until both architectural and structural solutions were satisfactory and within budget. Similarly, the air-conditioning of Prudential Hall was considered and reconsidered, involving external engineering experts to ensure the most appropriate solution that met the acoustical criteria was selected.
Every design solution was costed and, where necessary, value engineered during each design phase. During the bid of each package of work, whether it was on budget or not, the contractor was involved in reducing costs while maintaining quality. Ultimately, on-site success was achieved by the partnering and interaction of owner, design team, and on-site architects and engineers with the construction manager and the contractors. As in the design phase, the client was key to partnering amongst the project team, so that the contractors realised the project goals and achieved the expectations of the client and design team for high quality construction within the costs agreed at bid.

4. Prudential Hall.

Structural design

This was driven by four fundamental criteria: acoustics, intimacy, budget and schedule. The N-1 acoustic criteria meant that the halls would have to be completely isolated from surrounding structures.

A 'box-within-a box' concept was developed - double concrete masonry walls separated by a minimum 3ft (0.9m) air space and double slabs at the roofs.The desire for patron/performer intimacy drove the floor-to-floor heights at the balconies. To maintain views to the stage, the closer to it a balcony is in plan, the lower it must be in elevation. Once the balcony elevations were set, they were constant throughout the project to maintain access for handicapped patrons without needing additional vertical transportation. The final floor-to-floor heights were 10ft 9in (3.28m) at the ground floor, 11ft 10in (3.61m) at the second level, and 13ft (3.96m) at the upper levels.

Steel v concrete - the age-old question

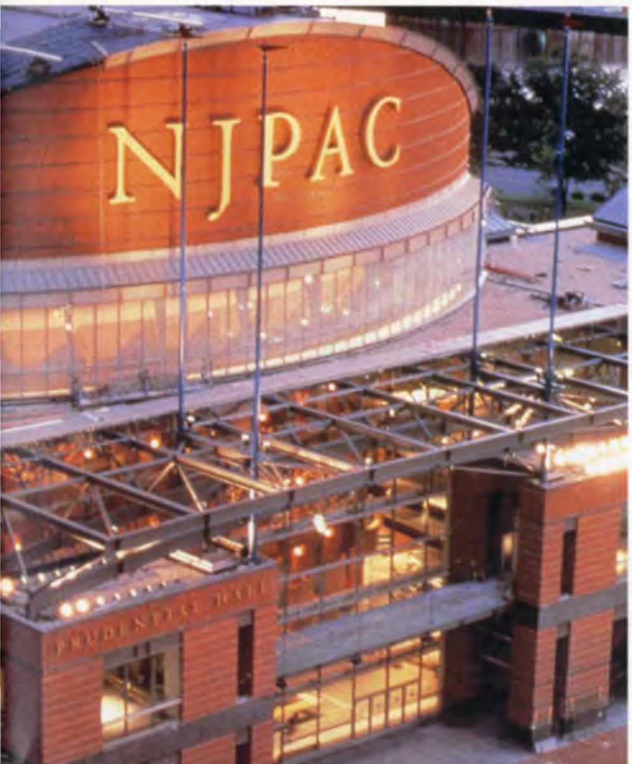
Once the architectural massing and the acoustic 'box-within-a-box' concept were established, the choice between concrete and steel was critical. The mass required for acoustics and vibration control at the balconies meant that concrete and/or masonry had to be given serious consideration. However, steel was chosen for the above grade structure (with concrete for foundations, basements, and pits) for the following reasons:

- Steel was already needed for the long-span roofs over the halls and lobbies, and use of it alone would minimise the number of trades during construction.
- The severity of East Coast winters meant the building had to be enclosed as soon as possible to allow the interior trades to work through the winters. Steel is faster to erect than concrete.
- There is very little repetition of concrete formwork on a theatre project, which would have increased the schedule and cost.

System for the Prudential Hall

The two performance halls and banquet/ rehearsal hall were separated from adjacent structures by acoustic/seismic joints (Newark is in seismic zone 2A) to limit transmission of structurally-borne vibrations. The masonry walls forming Prudential Hall's 'box-within-a-box' were then located. The outer walls run past the floors and take their load both vertically and in the plane of the wall down to the foundations. Only the out-of-plane loads needed to prop the walls are resisted by the steel frame, thus reducing the gravity and lateral loads by 20%. The inner walls of the box - a series of walls completely supported by the steel frame and shaped for acoustics - go from floor to floor, in various locations according to the room geometry. The acoustic void between the walls was the logical place for columns and braced frames, as well as building services, and co-ordinating the void became a key element in the successful coordinated design for the hall.

5.
Computer-generated image of Prudential Hall structure.

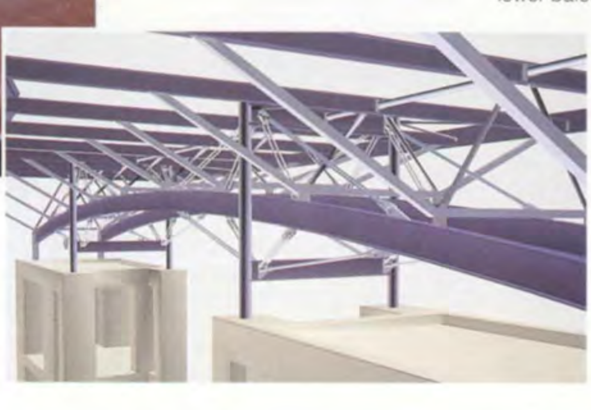


6.
Exterior of main lobby.

The hall's lateral system consists of braced frames around all four sides of the flytower, and horizontal diaphragms. Concentric braced frames were chosen because of their stiffness compatibility with the masonry walls, and their placement was critical due to:

- linking the various levels and areas of the building together into a unified whole
- locations of door and service openings
- steel erection.

The flytower, as a self-supporting box, was erected first, with the auditorium side of the hall 'leaned' against it, and by tying the auditorium to the flytower side walls, there was no need for bracing along the sides of the auditorium where multiple doors were needed. The rear wall of the auditorium was critical from a stability standpoint, and was further complicated by the rear cantilever of the fourth balcony back towards the lobby. The solution was to brace up the entire length of wall along the back of the fourth tier up to the attic and roof, which minimised the overturning effect of the braced frames on the cantilevered beams and tied together the balcony beams. The lateral load transfers through a slab at the bottom of the fourth tier beams over to the braced frames at the rear wall of the lower balconies and down to the foundations.



7.
3D computer-generated image of external lobby truss.

8. Stage.

Proscenium structure

The proscenium bracing between auditorium and flytower, creating the latter's fourth side of bracing, was a particular challenge in both design and schedule. The structure here had to carry the flytower roof, attic, gridiron, loading galleries, and fly galleries, and laterally support half the auditorium and half the flytower. Architecturally, it is the surround to the stage opening, the focus of all eyes. The solution was to separate the proscenium wall's primary and secondary structures. Two major exit stair towers were located with one of their walls aligning with the edge of the flytower. A portal frame of two double-bay braced frames at each side was created, connected by a 20ft (6m) deep truss.

Balcony structures

The design requirement of long 25ft (8m) balcony cantilevers supplying air to the patrons, and the architectural desire for coffered ceilings and a thin front edge to the balcony, combined with the tight floor-to-floor height and stairs at the balcony sides cutting across the radial pattern of seating, created an engineering and co-ordination challenge. The key to the solution was a 12ft (4m) spacing between the columns under each balcony cantilevered beam. That eliminated the need for girders, allowing supply air to feed easily between the beams radially into the Hall.

To provide an economical design, the location of the rear masonry wall at the interior side of the hall had to take into account that the balcony cantilevers needed backspans. The wall could not align from floor to floor, and the narrowest air void section at the second tier was not sufficient to be an adequate backspan. The solution was a series of propped cantilevers, where the column closest to the stage stepped back at each tier, going upwards. The rear crossover corridor in the lobby at each level was used to make a horizontal diaphragm carrying the unbalanced thrusts to the sidewalls, where it ties into the braced frames at the sides of the flytower walls.

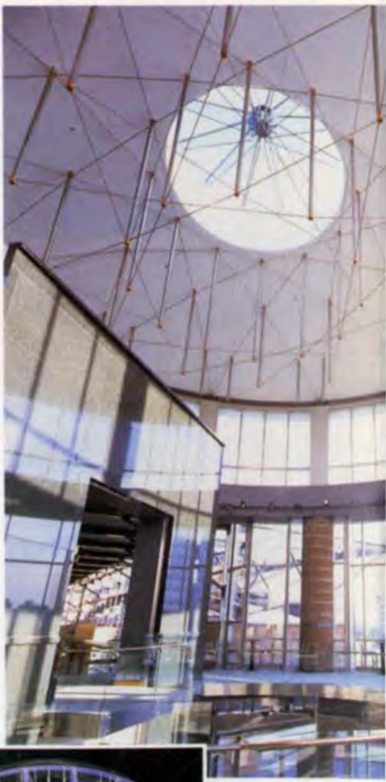
Vibration was a significant concern for the balcony structure. At scheme design, before any detailed vibration analyses, the deflection criteria for the balcony beams were set at 0.5in (12mm) under live load so as to define the architectural envelope and the steel budget. At the end of design development, after balcony models were complete, a full vibration analysis was carried out. The final solution involved thickening the vertical concrete of the seating risers and slightly adjusting the tapers of the original beam sizes.The final challenge in the balconies was documenting the structure for construction. To integrate the tapered steel beams, side stairs, air supply, and varying coffered ceilings, we developed the centre of a 3D model which was then imported into a 2D model, to allow the design team to extract dimensions for final construction coordinates.

Main lobby structure

Unlike the rest of the project, the main lobby and rotunda were not defined by acoustics requirements; the acoustic consultant determined early on that the main lobby should not be structurally attached to the main hall. A double cantilever scheme was selected with the rear wall of the hall curved in plan, making the cantilevers vary from 15ft (4.57m) long at the centre of the lobby to 36ft (10.97m) at the edges. Architecturally, the vision was for the lobby-front elevation to recall a theatre proscenium, supported by two towers 60ft (18.3m) apart, with flagpoles extending outward. Across the top of the arch was a series of cantilevered planar trusses at 14ft (4m) centres with a constant roof elevation that varied in depth according to the arch profile. The deepest trusses were thus at the lobby sides where the roof had to cantilever furthest to reach to the hall's curving rear wall, and shallowest at the centre of the hall where the cantilever was shortest. By creating a double cantilever out of the trusses, the architectural vision of embracing Theater Square was achieved.

Rotunda roof structure

Located at the intersection of the major streets bounding the site, the circular entry rotunda was designed to be a critical element of the design. It was important to maintain the 'purity of the circle of arrival' and thus the structure played a key role. At scheme stage, the team developed half-a-dozen alternatives based on a ring beam round a skylight, 60ft (18.3m) aloft, but all were both structurally impractical and aesthetically inappropriate. The final solution was a prestressed, stainless steel, cable truss 'star', offset from the centre around the skylight, formed from 3.5in (89mm) diameter stainless steel struts lit from the perimeter ring beam, making the roof structure itself into a chandelier. By creating trusses spanning right across the circle, erection was simplified, and accomplished in a single day.



9.
3D image
of Rotunda.

Mechanical design

Prudential Hall

It was apparent from early design phases that the goal of stringent noise criteria, and the intimacy of the patrons to the stage, would require a unique solution to distributing conditioned air, without draughts, to the Prudential Hall. Locating the hall's three air-handling units (AHUs) - two for the auditorium and one for the stage - in two main rooms either side of the hall avoided large ducts crossing the space. The surrounding acoustic joint required them to be in separate structures to stop structure-born noise affecting the space.

The height of Prudential Hall and its compact arrangement led the design team towards an under-floor air supply strategy, one of the few in the USA. During design the client had concerns about draughts and the system meeting the strict acoustic criteria. A detailed CFD model analysis, plus extensive research into European halls with similar systems and two days' full test of the proposed diffusion device (a perforated seat pedestal), produced a performance-based specification on which the air handling was bid.

Air is supplied via pressurised plenums under the main floor and at each tier, co-ordinated with the structure, lighting, and architectural ceilings. To maintain the tight floor-to-floor heights but minimise horizontal ducting, multiple vertical duct shafts were provided at the balcony levels between the acoustic double walls. Acoustic plenums at each level, where these ducts penetrate the walls, eliminate any break-in sound or regenerated noise from balancing dampers. Other acoustic plenums and silencers throughout the air-handling systems that serve noise-sensitive spaces prevent break-in sound and fan noise reaching the performance space. Air is returned from the auditorium at high levels just below the attic space and also from the rear of each balcony.

Victoria Theater

Due to its limited height, Victoria Theater is served conventionally by two units, one for the auditorium and one for the stage. Air comes in at high level through a series of concealed slots created by trimming the concrete between the flutes of the architecturally exposed metal decks. Air is returned at low levels, below the balcony and through architectural grillage at the front of the auditorium. The same system was also adopted for the banquet/rehearsal room, another sound-sensitive environment.

Lobby and rotunda

The fully-glazed main lobby is south-facing and thus very sensitive to exterior temperatures, which range from below 0°F (-18°C) in winter to very hot and humid summer days. The glazing is recessed from the façade with appropriate shading, with an intermediate exterior balcony between the towers at each end of the lobby. The towers are linked structurally for wind support of the glass façade by three 18in (460mm) diameter steel pipes at the quarter points of the elevations. These pipes conduct conditioned air across the glazing to eliminate downdraughts and winter condensation. CFD modelling was also used here to determine optimum placement of the supply and return air terminal devices. As in Prudential Hall, this area has a unit on each side to limit large duct penetration.

Smoke control

Smoke is exhausted mechanically at both stage areas and all lobby spaces, where make-up air is supplied naturally through electrically operated doors. In each stage the return air system is utilised for make-up air, supplied by a separate fan. Smoke exhaust fans connected to the supply ducts remove the air. The goal was to limit the number of penetrations (acoustical weak links) into the stage areas, and locate connections to the outside as far away as possible.

Central plant

As at Cerritos, an acoustically decoupled plant-room tower houses the central hydronic equipment. Two 500-ton centrifugal chillers, with primary and secondary circuits, supply chilled water. Forced draft cooling towers are provided in a well at the mechanical room roof. Hot water comes from two 6.3M BTU/hr forced draft water tube boilers through a primary pumping system. As well as reheating coils, the hot water is also used for preheating outside air and therefore contains 30% propylene glycol.

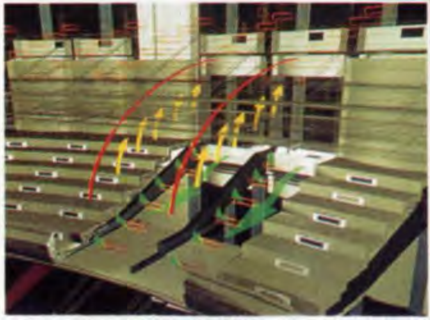
Electrical design

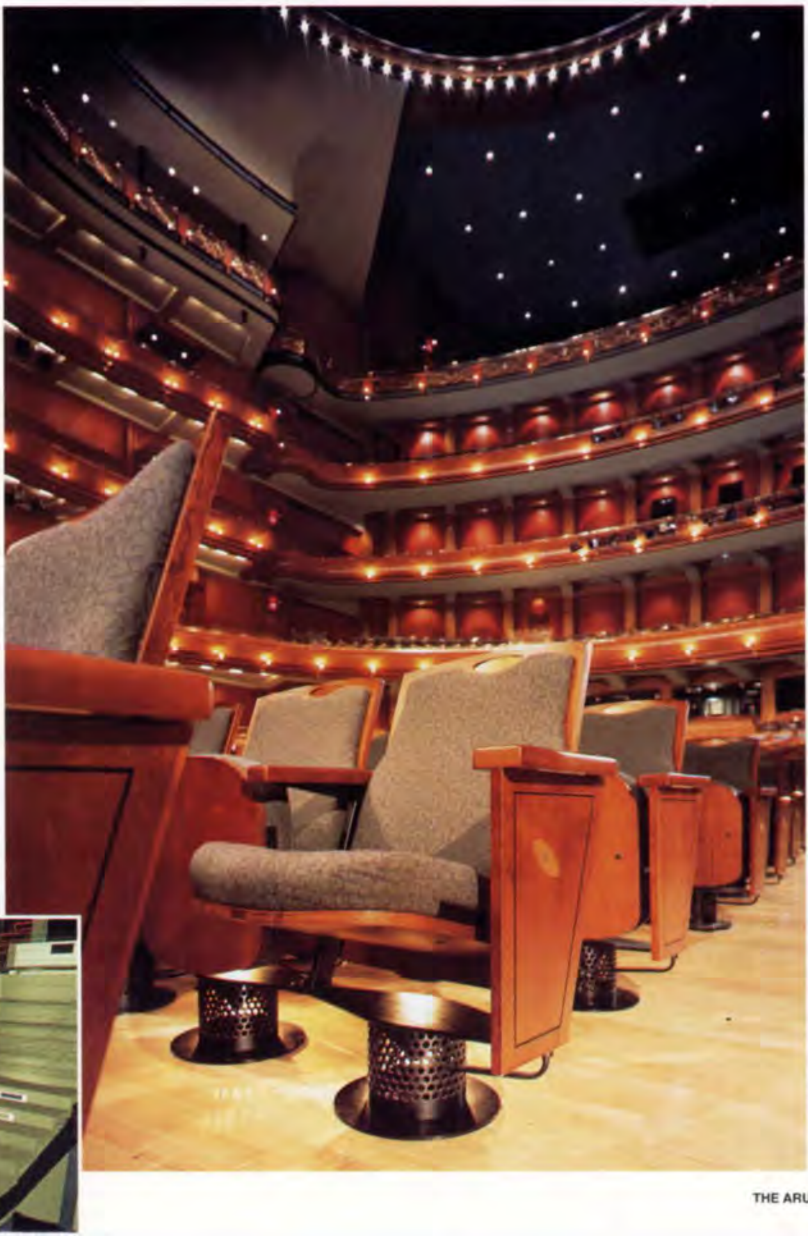
Much of the theatre electrical equipment is sensitive to electrical noise interference generated by heavy equipment like chillers, AHUs, pumps, and large motors. To eliminate this and provide flexibility in the high theatre equipment loads, one of the three incoming servers was selected to serve the theatrical lighting, sound equipment, and other associated servers. The second supplies all the central plant equipment and AHUs, whilst the third, with a smaller capacity, serves the administration areas and other back-of-the-house services.

10 above.
Detail of tensegrity structure of Rotunda.

11.
Interior of Rotunda.

12 below:
Computer-generated image of air supply in Prudential Hall.





13.
Underseat air distribution through Prudential Hall.

The theatrical lighting runs at 120/208V; three-phase, four-wire and dedicated stepdown shielded transformers supply the voltage. To achieve the strict noise criteria in the performance spaces, various noise reduction measures were employed, including:

- a slow rate of rise of the dimmer systems, making the filaments inside the theatrical lighting quieter during dimming
- electrical rooms outside the acoustic joints
- special low voltage transformers with dimmer facilities
- all penetrations from electrical rooms into auditoria organised and detailed to minimise sound transmission.

To keep the sound and electrical power systems apart, special attention by the design team and the contractor was paid to developing separate risers and routing throughout the building and identifying which equipment could be linked to the same electrical supply. Each hall has a sound control room and common sound rack that allow sound to be broadcast simultaneously in both halls.

For emergency purposes, the sound system is connected to the fire alarm system, for which separate speakers are used.

A unique aspect of the electrical design was the distribution to the hall ceiling; this consists of multiple panels, laid horizontally for concerts. In other performances, they are turned vertically for moving upstage and storage. Within the concert ceiling, there are over 170 2000W light fixtures, each with its own dimming circuit. There are nearly 400 wires between the dimmer panel and the concert lights. The panels need to be positioned rapidly and staff do not have time to plug in light fixtures, so the wiring to the lights has to be permanently linked to the panels. The bundles of flexible multi-core cables hang from a 'curtain track' attached in turn to the nearest structural beam. A terminal cabinet is provided about 54ft (16.5m) above the stage floor, where the circuits emerging from the dimming room terminate. From here the circuits are divided into groups which then terminate at multi-pin connectors. The flexible multi-core cables are plugged into the connectors and run up and down the stage along the track. As the concert ceiling turns into position, the tracks expand or retract in a similar manner, allowing the circuits to be connected to the concert ceiling in a permanent position without any site reconnection. The multi-pin connectors also allow for future circuit changes.

The building is networked via dedicated fibre cables to a central theatre hub for ticket sales. A central telephone switch is provided for the administration staff and sales office, carrying automatic pre-recorded news and messages, voice mails and other essential services.

Plumbing design

These systems also reflect the strict noise criteria and tight distribution spaces. Pipes containing moving liquids had to be kept out of noise critical spaces, which led to acoustic hangers for both rainwater pipes and soil drains from the toilets being provided where it was impossible to locate the pipes completely away from noise-sensitive spaces. The drains are hung at their highest point and tied back to the slabs on the non-acoustically sensitive side of the acoustic joints. Rainwater from the auditorium roofs is guttered away to cascade onto lower roofs over non-sensitive spaces.

14. Interior of stage.

Domestic hot water is generated centrally and located in the mechanical tower adjacent to the kitchen, the heaviest point of use. To route hot water, chilled water, and heating hot water piping to the west side of the building without passing through the auditorium, an isolated crossover zone was created behind the stagehouse.

Fire protection is achieved via a variety of methods; with conventional charged sprinkler systems used in the majority of the spaces. The local BOCA code (Building Officials Code Administration) does not require auditoriums to be sprinklered. The stages are a different situation, having a combination of double-interlocked pre-action systems with 35-second delay and deluge devices. The delay enables the maintenance personnel to prevent activation in case of false alarm caused by a stage activity.

Conclusion

On 18 October 1997 the Center's Gala Opening was held before a full house. The performance was extremely successful, with the Center's flexibility being demonstrated by the number of different performances and acts. After seven years' work on the project, it was extremely fulfilling to watch the patrons enjoy the facility and appreciate the architecture and engineering.The project would not have been such a success had it not been for the client's leadership and the spirit of co-operation and partnering by all who were involved. It is also very gratifying that the project has already received three awards: from the New York Consultant Engineers Council, from the American Consulting Engineers Council and one from the New Jersey Concrete Society.

Reference

(1) JOFEH, C. Cerritos Arts Center, California. *The Arup Journal, 26*(2), pp17-21, Summer 1991.

Credits

Client:
New Jersey Performing Arts Center

Architect:
Barton Myers Associates

Consulting engineers:
Ove Arup & Partners Tom Barker, Jonathan Bell, Peter Budd, Jacob Chan, King-Le Chang, Waylon Cheung, Yen Chong, Keith Chung, Tony Cocea, Carolyn Comer-Gmelich, Rolando Constantino, Phil Crompton, Bob Emmerson, Caroline Fitzgerald, Richard Gargaro, Mel Garber, John Gautrey, Kathleen Gibbons, Nancy Hamilton, Mike Hammer, John Hewitt, Richard Hough, Scott Hudgins, Morgan Lam, Alan Locke, Anait Manjikian, Josef Negat, Phoebe O'Brien, Alan Ravandi, Sharlene Silverman, Nuran Sinanyan, Melani Smith, Ian Stuart, Jose Tia, Jacob Tsimanis, Dan Ursea, Rodney Walden, Victor Wirth

Construction manager
Turner Construction

Cost consultants:
Donnell Consultants Inc

Theatre design:
Jules Fisher Associates

Acoustic consultants:
Artec Consultants

Associate architect:
Wilson Woodridge Architects

Lighting design:
Jules Fisher & Paul Marantz Inc

Civil engineering:
Paulus, Sokolwski and Sartor Inc

Landscape architects:
Benjamin Thompson & Associates

Local engineering practice and code advice:
DVL Consulting Engineers Inc

Illustrations:
2, 3: Barton Myers Associates
1, 10, 11, 13, 14: Fred Charles
4, 6, 8: David Street
7, 9: Scott Hudgins
5, 12: Ove Arup & Partners California

Wenko-Wenselaar headquarters, Hückelhoven

Michele Janner

1. Aerial view, March 1997.

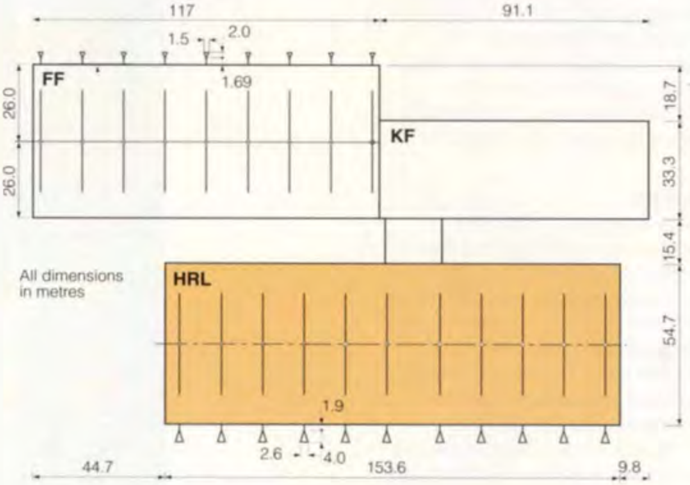
Introduction

In the mid-1990s Wenko-Wenselaar, a leading German importer and repackager of household goods, planned a new headquarters building at Hückelhoven, a small town near Aachen, Westphalia. The project comprised an 18 000m^2 office, storage, packaging, and loading/unloading complex, and Wenko-Wenselaar commissioned Michael Juhr of Wuppertal as architect, with Arup GmbH as structural engineer for all seven phases. For two of the phases Arups was also asked to carry out a building physics analysis, advising on the performance of the building skin, etc.

Besides a requirement to produce a cost-efficient design with a high degree of flexibility, the client also specified the following facilities:

- a 16m high pallet storage area of about 8500m^2, with capacity for future expansion (building **H**och**R**egal**L**ager)
- a packaging area of c5000m^2 (building **F**unctions**F**läche)
- a loading / unloading area of about 3500m^2 (building **K**ommissionierungs**F**läche)
- some 1000m^2 of office space on two floors (within building FF).

The three buildings HRL, FF and KF form the total project. HRL and FF both have cable-suspended roofs whilst KF, due to its smaller span, has a different structural system. This article focuses mainly on the largest of the three buildings: HRL.



2. Location plan.

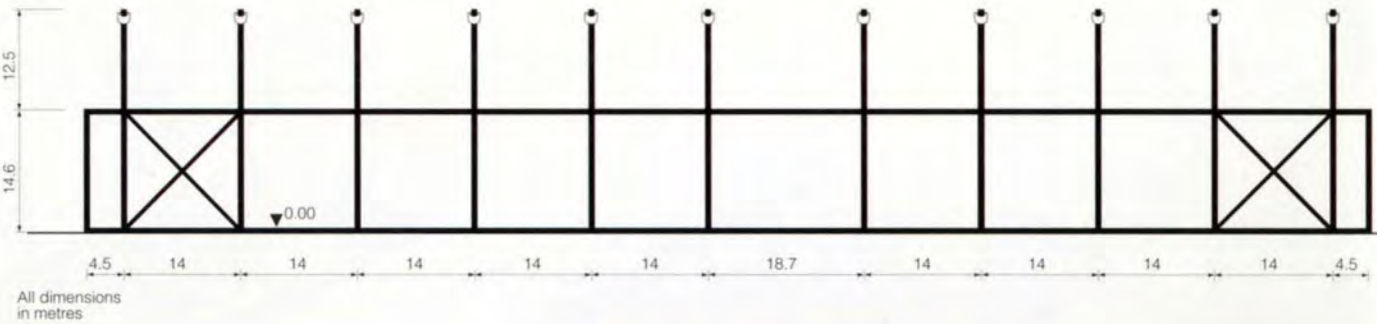
Materials and fire safety

To achieve maximum flexibility, all areas had to be as column-free as possible, which necessitated long-span roof structures. The building was to be sprinklered, so there was no requirement for structural fire resistance, and as the local soil conditions were poor, a steel roof structure - relatively light in weight - was chosen. The structure of the office area, the 'building within a building', had to have 90 minutes' fire resistance. Here the walls were constructed of in situ concrete, with precast decks, and the columns and beams as composite sections to facilitate the structural connections to the main steel structure.

For the steel roof, various types of steel structure were analysed. A cable-stayed solution allowed the use of small roof beams which reduced the building's height (and thus its façade area and total volume). The final design established a compromise between the height of the roof beams and the amount of cable supports and consequent roof perforation.

Soil conditions and roof structure

Packing pallets in racks up to 14m high, using automatic guidance systems for the lift trucks, required stringent design criteria for differential settlement of the floor slab. Because of the poor ground conditions the topsoil had to be removed and replaced over the total construction area, in some place to a depth of over 1.5m. By 'hanging' the roof, the number of foundation pads was reduced to a minimum, which also minimised the amount of ground improvement needed. Between the façade columns and the main central columns, however, differential settlement was still anticipated to the extent that it would cause significant change in the force distribution of the cable-supported roof structure. Settlement of both sets of columns is therefore being monitored to determine the amount of post-tensioning needed. To facilitate this, the tensioning devices of the rods are located just above roof level.



3.
Elevation of building HRL.

Structural concept

This consists of separating the vertical load-carrying structure from the horizontal one, together with repetition of the structural system.

Longitudinally, horizontal stability and stiffness are provided by cross-bracing in the roof and the façades at both ends of the building. Across its width, however, the building is held every 14m by large spaceframe columns along one side, linked at roof level to the main roof beams. To maintain maximum flexibility inside, these spaceframe columns are located outside the building.

The building is therefore formed from repeating structural units 14m long and c56m wide, placed one after the other throughout the entire length of 154m. Such a structural unit is stiff and stable both vertically and across the width: all the vertical loading is carried by pairs of façade columns 56m apart plus one main column in the middle, each of the latter extending 12.5m above the roof and carrying the main roofbeam via four steel rods. For the snow loadcase the main roofbeam is sustained by this additional support; in the case of wind uplift the 30m unsupported span is adequate. The secondary roofbeams, supporting the roof metal deck, act as 14m long spacers between the structural units. If future expansion of the building is required, additional complete structural units can be added.

Façade perforation

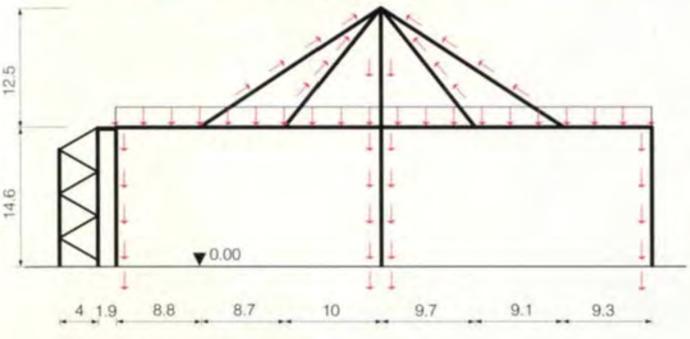
Since only horizontal forces are transferred between the façade column inside and the spaceframe column outside, the roofbeam could be split, separated by hard plastic isolators and connected by just two bolts in order to reduce the cold bridge that would otherwise formed by the continuous roofbeam. On the other hand, the transfer of only horizontal loads onto the spaceframe columns seemed to result in the need to design large foundation pads (10 x 4 x 1.5m) to take up the overturning moment. However, even if roof loading were carried down by the stabilising spaceframe columns, the large foundation pad remains necessary, since the roof loading on the façade columns almost reaches zero in the asymmetrical roof loading case.

5.
Spaceframe column.

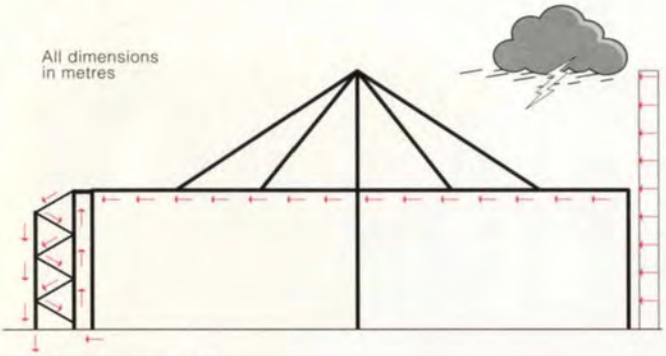
4.
Spaceframe column connection to foundation.

6.
Connection details at roof level before the exterior cladding was put in place.

7a & b.
Cross-sections of building HRL showing loadpaths.



a. Loadpaths Vertical



b. Loadpaths Horizontal

9.
The clear internal height is 14.6m.

8.
The 12.5m main column extensions at roof level.

Roof perforations

The main columns had to be continuous through the roof, because of the large bending moments and shear forces in these columns at roof level which occur in the asymmetrical roof loading case. Here, a special Arup study recommended the insulation of these columns beyond a height of 1m above roof level, to reduce the possibility of condensation on the interior steel structure.

Main column top-detail

Special attention has been paid by the architect and Arups to what is probably the most important roof detail, the connection of the rods to the main column. The difficulty lay in the difference of proportions: how to connect a 57mm rod to a 762mm column in a sensible and elegant way. The combined horizontal and vertical solution was chosen to make the visual impression more individual. It should be noted that for the horizontal detail the lower of the two connecting plates had to be welded onto the column itself to take up the deadweight of the rod, as the rod is loaded in compression.

Conclusion

Work began in August 1996, with the replacing of 51 400m^3 of soil. In November 1996 steel erection started, and was finished about three months later. In August 1997 the entire building was finished. The total cost of the project was about DM23M. Of this, the steel construction totalled approximately DM3M.

Credits

Client:
Wenko-Wenselaar & KG PRODLOG

Architect:
Michael Juhr

Structural and building physics engineers:
Arup GmbH Düsseldorf
Monika Beyersdorff, Brian Cody, Michele Janner, David Lewis, Gary Thomas, Constant van Aerschot

Mechanical engineers
HTW

Geotechnical engineers:
Friedrich & Dr. Krämer

Main contractor:
Spannbeton-Oevermann GmbH & Co

Principal sub-contractors:
Steel: BMS
Metaldecking: Combau

Illustrations:
1: Hubert Harst
2, 3, 7: Peter Speleers
4-6, 8, 9: Michele Janner

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