THE ARUP JOURNAL

2/1997

ARUP

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Vol. 32 No. 2
2/1997

Published by
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London W1P 6BQ

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Front cover:
The Commerzbank, Frankfurt, (Photo: Ian Lambot)

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Hulme Arch Bridge (Photo: Positive Image)

Commerzbank, Frankfurt **3**

Peter Bailey
Harry Bridges
Paul Cross
Gabriele Del Mese
Chris Smith
Seán Walsh
Chris Wise

The new headquarters for Commerzbank sets fresh standards of environmental friendliness for a high-rise office building in terms of low energy consumption, the creation of sociable, people-oriented working spaces, and a positive contribution to the townscape within which it sits. Ove Arup & Partners' innovative structural design was central to realising these aims, as well as being conceived in a rationalised 'kit' form which contributed greatly to cost- and time-saving construction.

IT for Scottish Equitable HQ, Edinburgh **13**

Daniel Grimwade

Arup Communications advised and assisted Scottish Equitable plc on all aspects of the IT and communications for their 30 000m^2 new head office, including the fundamental design issues relating to IT and communications, the cabling system, the data network design, choice of a new telephone system, the staged move into the new building, and the continuing management of the communications system.

Hulme Arch Bridge **15**

Naeem Hussain
Roger Milburn
Ian Wilson

This landmark bridge, combining the cable-stayed and arch structural principles, was designed by Chris Wilkinson Architects and Ove Arup & Partners to a commission from Hulme Regeneration Ltd with Manchester City Council. The client's intention was to create a highly visible centrepiece to mark the regeneration of this hitherto run-down area of southern Manchester.

Upgrading University Hospital of Wales, Cardiff **18**

David Hay
Ray Lake
Graham Phillips

Throughout the 1990s Ove Arup & Partners has been project manager and lead consultant for a complex programme of remedial works to this hospital, including fire precautions upgrading to all buildings, refurbishing and extending the dental hospital , improving existing wards, refurbishing lifts, installing a new security system, and provision of new wards, a multi-storey car park, a heart research facility, and accommodation for the Trust for Sick Children.

The Cadbury confectionery facility, Chudovo, Russia **21**

Mark Bartlett
Robert Lindsay
Fred Loterijman
David Storer

Russia is Europe's third largest market for confectionery, and since the break up of the Soviet Union Western manufacturers have established production facilities there to satisfy the Slavic sweet tooth. Ove Arup & Partners acted as lead consultant and engineer for the full building and civil engineering design of this state-of-the-art facility for Cadbury Schweppes plc, which has now opened 150km from St Petersburg.

Commerzbank, Frankfurt

Peter Bailey
Harry Bridges
Paul Cross
Gabriele Del Mese
Chris Smith
Seán Walsh
Chris Wise

1. Commerzbank completed, May 1997. 2 (below left). The project logo designed by Arups shows the characteristic helical form.

The competition

'... the fashion of height needs questioning fundamentally.'
(Architects' Journal, *20 February 1997)*

The new headquarters of Commerzbank, one of Germany's leading banks, is now the tallest office building in Europe. Unusually for a high-rise building, environmental friendliness was the fundamental design criterion, and the structural and environmental engineering systems were major factors in the evolution of the overall design.

The building was conceived in the German political and social environment after re-unification. In Frankfurt, the Green Party has power; Commerzbank was encouraged by the politicians to make its new HQ a demonstrably 'green' building, and the brief for its international design competition in early 1991 stated that 'the environmental friendliness of the design shall be as important as functional worth'.

12 practices were invited to enter: nine from Germany, two from the USA, and one from Britain. The team of Sir Norman Foster & Partners with Ove Arup & Partners (structure and geotechnics) and HL Technik (environmental services) won; Roger Preston & Partners were subsequently appointed as lead environmental engineers.

At the client's request, Arups formed a joint venture with the Darmstadt practice Krebs und Kiefer. This team, led by Arups, undertook concept, scheme and detailed design (including the mandatory proof engineering calculations), helped obtain the Construction Permit, and delivered structural documentation for tender. Arups were also traffic, wind and fire safety engineers. The joint venture worked extremely well throughout the project.

The concept
Can tall buildings be green?

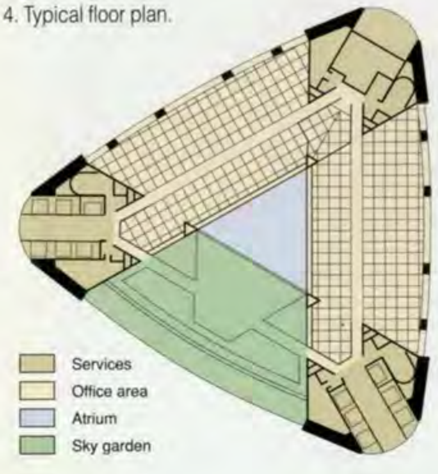
Frankfurt's City Plan has a tall building ethos in apparent conflict with its green politics, and this had to be reconciled at the project's outset; Commerzbank was designed 'in the real world', within existing urban guidelines. Whilst design teams often challenge clients' briefs, neither sites nor business circumstances can usually be changed, no matter how morally persuasive the case. The design team fully supported the need for environmentally aware urban planning, and tried to influence this positively where it could, particularly through the way the new HQ opens itself to the city to allow street level access and interaction.

Interestingly, the project's overall financial viability was improved by its approach to green issues. The capital cost was more than offset when the city granted planning permission for Europe's tallest building with a greater plot-ratio than originally expected. The extra built area meant the client need not buy another expensive site in Frankfurt's financial district, and could house all 34 head office departments on a single site (Fig 3).

3. Site plan.

Commerzbank comprises a 56-storey office tower, 299m from street level to the tip of the mast; a three-storey basement; a six-storey building east of the tower, containing apartments, offices, retail, and car-parking; an auditorium; a partially enclosed public plaza; and refurbishment of existing adjacent historic buildings. The design radically departs from traditional high-rise planning, working practices, and constructional thinking, and needed new engineering solutions. The aim was a structure fully integrated with the architectural and environmental concepts, elegant, and fast and economical to construct. Achieving that modest aim was a considerable challenge and all the structural systems were developed iteratively over nearly three years.

4. Typical floor plan.



The final project has many unusual features for a tall building, including:

Sense of place

- innovative planning and working arrangements: office areas in elevated 'villages' sharing communal 'sky-gardens'
- an internal planning strategy encouraging interaction between people and departments, and giving a sense of orientation - unlike a conventional central-core tower where everyone looks outward but has limited visual or physical contact with anyone else except in the lift
- column-free, open-plan floors around the sky-gardens and a central atrium extending the building's full height to give natural light and cross-ventilation, and views from all directions
- an open entrance level blending with Frankfurt's urban fabric, creating a new public plaza for city-dwellers and Commerzbank staff alike
- a rational lift strategy minimising travel distances and encouraging short journeys during the working day.

Transparency

- The spiralling sky-gardens visibly express the building's green ambitions for natural lighting and natural ventilation.
- You can see right through the building from street level.

Deceptively simple structure

- first use of steel as main structural material on a major German high-rise
- perforated tube structural frame, creating the sky-gardens while efficiently carrying gravity and wind loads
- rational, mass-produced 'kit' of construction elements enabling maximum off-site production, and minimising site labour, learning cycles, construction time, and cost
- use of thermal mass of floor decks as buffer to minimise morning energy demand
- substructure piling of unprecedented type and depth
- sophisticated temporary works to maintain stability of the adjacent Commerzbank tower, founded on a high-level raft in the Frankfurt clay.

Very low energy demand

- It is the first naturally-ventilated tall office building - using local and global natural ventilation systems.
- High daylight levels minimise the need for artificial lighting.
- The internal environment integrates with an openable glazed façade controlled by the Building Management System (BMS), driven by the building's own weather station.
- Full use of passive and low-energy techniques gives very low energy consumption.
- High-quality working environment can be individually controlled and adjusted by Bank staff from their desks.
- Simple servicing strategy minimises horizontal service runs, giving minimum storey heights.

The sky-gardens and the helix

The tower plan is a rounded equilateral triangle, 60m wide. On any one level, one side opens to the sky-gardens, each four storeys high with spectacular views over the city, and linked to the central triangular atrium (Figs 4, 5). Facing the gardens are pairs of wedge-shaped office 'petals', each containing a working group of about 40 people. Office floors are glazed front and back, c16m wide, column-free, and flexible for open-plan or cellular layouts.

5. Sky garden, February 1997.

This compares favourably with other German high-rise buildings which only have shallow, single-sided spaces backing onto a heavy core, and a lot of 'dark' space only usable for support, storage, and filing. This is partly because German workplace regulations require occupants to be within 7.5m of a conventional external wall to receive enough natural light.

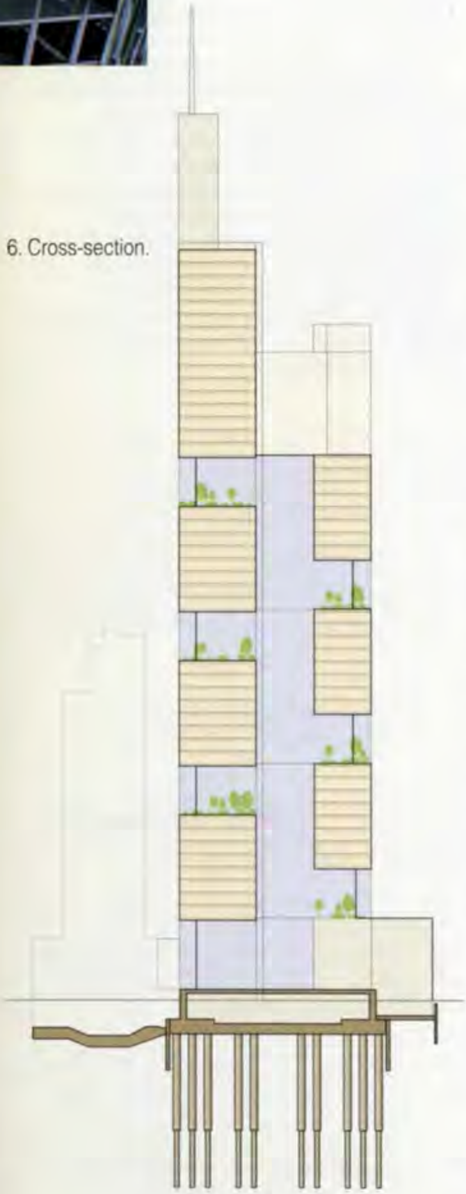
Every fourth level the plan rotates 120°, so that gardens on all three sides bring air and light to the office areas from every direction. The tower sub-divides into 12-storey 'villages' of about 650 people sharing three sky-gardens (Fig 6). The villages are stacked into the tower, creating a helix of offices and gardens which spirals on upwards to house directors' suites, lift motor rooms, and finally the upper service plant tower. Each village forms one environmental entity between glass floors across the atrium that provide fire separation and define internal ventilation and smoke control zones. In the original design, the atrium was completely open for 56 floors, but studies by Roger Preston & Partners showed this would generate violent vertical air currents, and a surfeit of hot air in the boardrooms at the top.

The garden spaces enhance the work environment by giving easily accessible recreational facilities inside the building, each landscaped to a different theme to help orientation and 'village identity'. The windows on each four-storey glass wall are essential to the whole building environment and so are opened and closed centrally by the BMS.

Environmental features
Natural ventilation

This was the key to the environmentally friendly design: to succeed in a high-rise building subject to high winds and significant stack effects was a significant technical challenge. All the offices can be naturally ventilated during temperate weather by openable windows in the external façade, in the atrium, and in the garden walls. Gardens and offices are linked via the atrium which provides the stack effect to drive cross-ventilation within each 12-storey village (Fig 7).

Natural ventilation is likely to be used up to 60% of the time, with target office temperatures of 20°C minimum in winter and 27°C maximum in summer. In extreme weather it will not provide good enough comfort conditions, so a complementary mechanical air-conditioning system has been installed. Each village has its own AHUs, comprising VAV supply and extract fans, thermal wheel, filters, cooling coil, heating coil, a humidifier, and fresh air/ recirculation dampers.



6. Cross-section.

The concrete floor deck's thermal mass averages out peak cooling demands by being a thermal buffer. At night, the concrete cools as the building is unoccupied. For the first part of the day, the cool concrete helps minimise air temperatures in the occupied spaces, removing the need for active cooling.

The mechanical ventilation works in conjunction with chilled ceilings or perimeter heating. The former have both a convective and radiant cooling effect, which enables comfort conditions to be achieved with a higher air temperature than a conventional all-air system.

Natural lighting

The large garden and atrium volumes raise light levels at work-stations round the atrium to that aproaching an exterior day-lit space. This gives significant energy economies as artificial lighting is a major energy user and heat generator.

The façade

This mediates between the surrounding environment and the workplace as a climate modifier to smooth the fluctuations of nature. After many design and cost iterations, the completed façade has a 200mm ventilated cavity with an opening double-glazed inner skin, hinged at floor level and motorised to allow the window to tilt in at the top. The outer skin, of single-glazed 8mm laminated safety glass, forms a screen to reduce air pressure fluctuations. The cavity is ventilated by continuous slots 125mm wide at the top and bottom of each floor, air flow being driven by the stack effect over a single storey. The ventilated cavity contains motorised blinds for solar shading, operable by the occupants. The internal panels are side-hinged for cleaning access to the blinds, and to the outer skin.

Early design concepts had summer air extracted via the cavity to remove solar gains, and warm air in winter supplied to the cavity, warming the glass surface and counteracting downdraughts from the open window. The final design, however, is essentially passive: more heat can build up in the cavity during summer, but the screened tilting window gives greater protection against rain and wind. Occupants can normally choose to open or close windows. In severe external conditions (wind, pollution, high or low temperature) they are closed automatically by the BMS, which constantly gathers data from the building's own weather station and seals the façade in zones.

Building Management System

All environmental systems are controlled by the BMS, zoned into the 12-storey village units and informed by weather stations at four levels. The BMS also monitors internal garden temperatures and initiates underfloor heating in bad weather.

Energy advantages

The advantages of choosing natural ventilation, maximum daylighting, and a ventilated façade are estimated as:

• cooling energy:	65% saving
• energy cost:	50% saving
• installed cooling capacity:	about 10% lower.

Superstructure

'... if the sky falls, the pots will be broken.'
(Spanish proverb)

An elegant structural solution aims to enhance building form and improve functionality; the Commerzbank superstructure attempts to achieve this by creating spaces in which green aims of natural light and natural ventilation can be sustained.

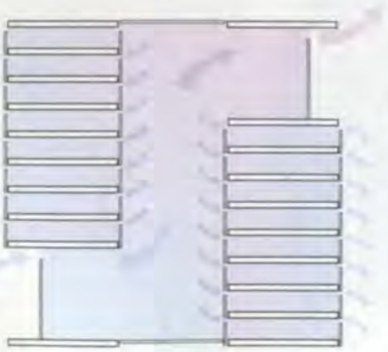
Transparency is achieved by the following features:

- the 200m high central atrium and light-well
- multiple four-storey high column-free sky gardens
- a five-storey high column-free entrance lobby
- column-free office space
- bracing-free windows
- no central core, allowing views through the building.

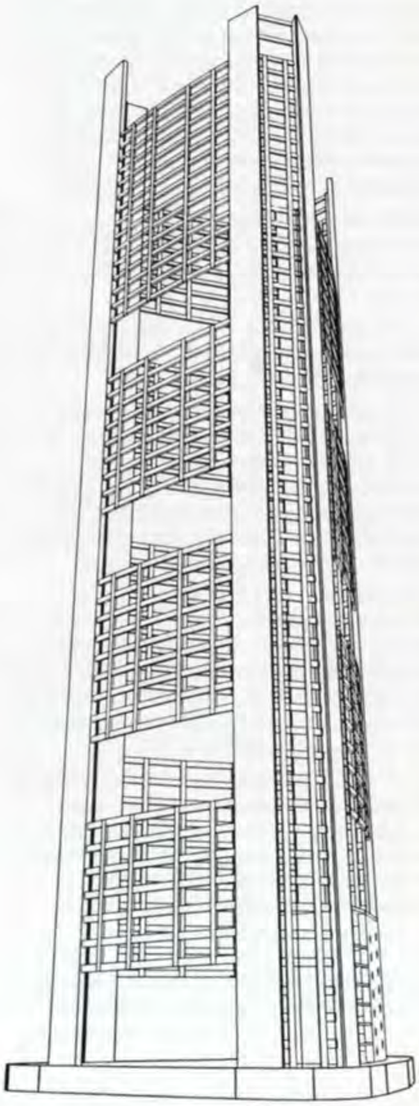
To realise all these, structural steel was the only viable material, and from the outset a mass-produced 'construction kit' was the aim, to make site work as easy as possible.

Tower perimeter structure

For efficiency, the main lateral and vertical load systems are combined. A perforated framed steel tube around the perimeter gives lateral stability, and acts as a giant repeatable transfer system to carry floor loads 34m across the sky-gardens. The tube comprises three pairs of massive composite steel and concrete 'core' columns at each corner, linked by vierendeel frames each eight storeys high on the three main faces of the building (Fig 8).



7. Principles of natural ventilation.



8. Right: Perimeter tube and vierendeel structure.

9. Wind tunnel tests.

Vierendeels were chosen to modularise the building cladding system; to avoid across-window bracing interfering with internal planning flexibility and the natural ventilation; and to give a calm and controlled exterior appearance. The final design significantly increases the façade's effective transparency compared to previous European high-rises.

The full building width resists overturning, the perforated tube structure being stiff vertically, horizontally, and torsionally. The helix means there are no 'soft' storeys, because a pair of vierendeels and a pair of core columns always adjoin a garden. As a result, sway under lateral loads is well controlled throughout the building height.

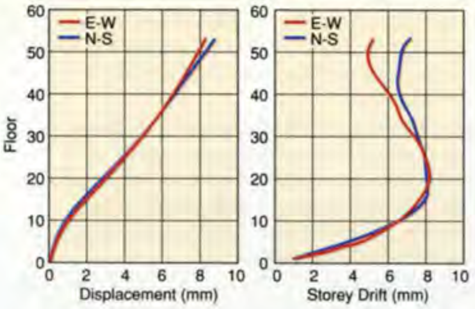
Wind load deriving from the supplement to *DIN 1055 Part 4* is the critical lateral design condition, and wind tunnel tests by RWDI, Ontario, Canada, confirmed the DIN wind loads to be conservative (Fig 9). Unfortunately, at the time of the design there was no way Frankfurt building law could admit the wind tunnel test results, so they could not be used to reduce the amount of steel in the building. For the rounded triangular form, the tests established a drag factor of 1.2 based on maximum building width, as well as pressure coefficients for the cladding system design.

Overall deformations are dominated by shear deformation of the vierendeels, which is significantly influenced by spacing of their columns.

- For wind loads, shear across vierendeel panels is effectively constant, so elements should be of equal size, at equal centres.
- For gravity loads, shear increases towards supports, so elements should be larger and closer together towards the ends of the vierendeel. Under gravity, the top and bottom chords of each multi-storey vierendeel also experience significant axial compression and tension, as in a more conventional truss.

In the final design, the spacing and size of the vierendeel beams and columns is a balance between these effects. The vertical elements are fabricated from plate, always 1m deep by 475mm wide, up to 65mm thick. The horizontal elements are always 1.1m deep by 475mm wide, up to 85mm thick. Steel is generally St52.

Several highly interdependent structural analyses and design studies were made of the superstructure. Three-dimensional static analysis of the framing system, using Arups' GSA program, included 2842 nodes and 4681 members to represent the composite perimeter structure. The model was conservatively assumed to be rigidly fixed one level below the Plaza. Separate models tested the behaviour and load-sharing of the composite structure under sustained and short-term loads, whilst finite element analyses determined the stiffness of typical main tube beam/column connections. These enhanced the total stiffness of the structure by about 10%.



10. Wind deflections.

To account for second order effects, the results of the 3D model were converted into an equivalent single cantilever model, including base rotations to represent foundation flexibility. This was calibrated against the full 3D model, and then used to assess the modal shape and period, wind gust factors, accelerations, and P- effects, which typically were less than 10% (Fig10).

The full building analysis showed that for a 1 in 100-year wind the tower was stiff and strong enough to maintain stability and comfort criteria. Maximum deflections, including P- magnification of the sway behaviour, were as follows:

- maximum deflections: 350mm (N-S) and 325mm (E-W)
- maximum building drift: height/560 (Target: height/500).
- maximum individual storey drift (at level 18): height/470 (Target: height/300).

Under vertical loads, deformations of the completed vierendeel system are comparatively small. Under the full design imposed load, the maximum vertical deformation at the centre of the 34m span is c18mm (span/1900).

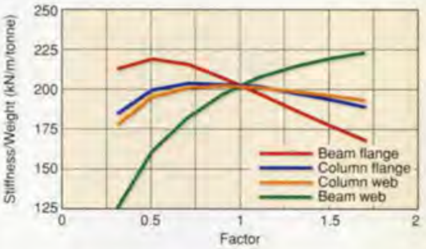
Dynamic analysis

Such a light building meant sway accelerations had to be acceptable to users, and the National Building Code of Canada design method was used. The first mode natural frequency is 0.17Hz (5.8 secs). Across-wind sway accelerations for the uppermost office floor are estimated to be 9.3 milli-g under the effects of a 1 in 10-year wind, assuming damping of 1.25%. This compares to a target for a building of this period of 15 milli-g (Fig 12).

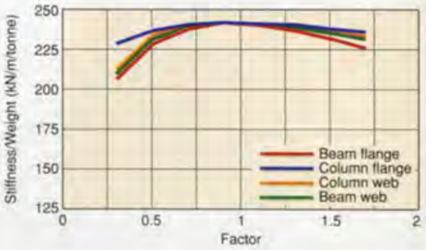
Optimising the structure

Throughout design, structural efficiency was optimised to maximum stiffness / minimum weight for each element of the perimeter structure. Efficiency was tested and iteratively improved by parametric studies using specially-written software.

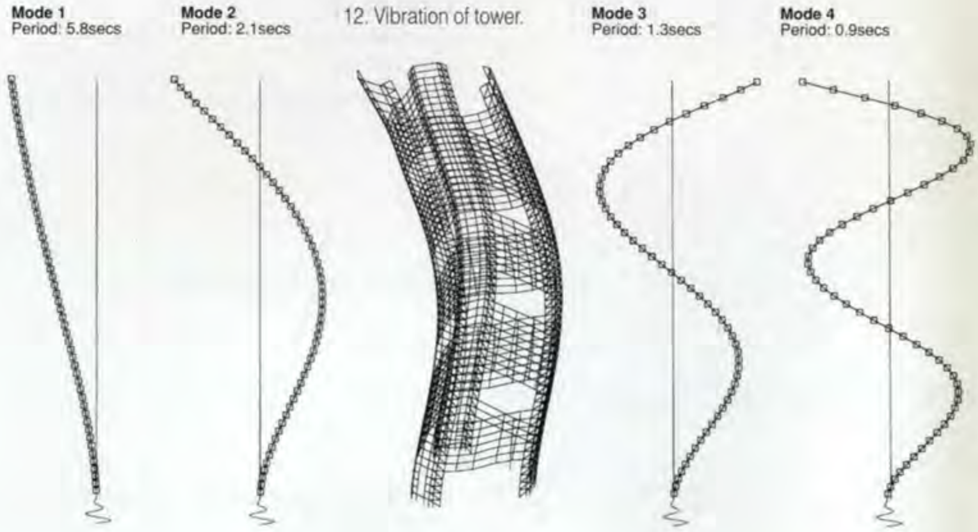
Fig 11 shows variations in structural efficiency of the vierendeel frames (measured as stiffness / tonne of steel) as flange and web plate thicknesses of members were altered. Each curve peak shows the maximum efficiency of each section. Before optimising, these were at different points and with differing sensitivities, showing some elements dominating the vierendeel system's performance. Optimising involved adjusting the properties of each component to ensure their peak performance coincided. This improved the structure's performance by some 20%, removing 770 tonnes of steel from the vierendeels - and saving the client a good deal of money. Similarly, optimum spacing of the vierendeel columns was derived as part of the evolving architectural form.

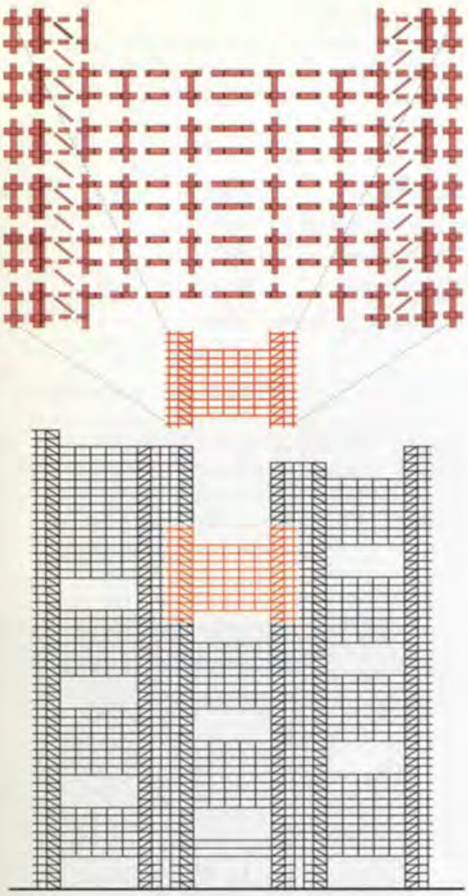


11. Above: before optimising and below: after optimising the structure.



12. Vibration of tower.





13. Vierendeel kit.

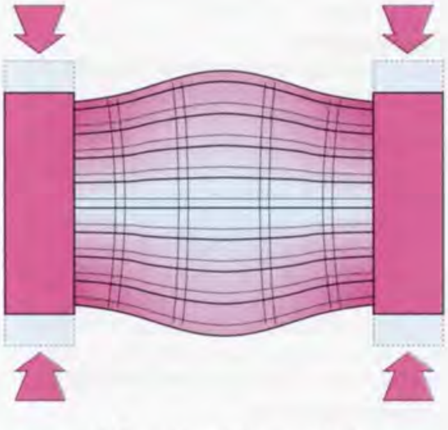
14. Factory joint.

15. Site joint.

Vierendeel kit

Adding wind and gravity stresses meant that all typical eight-storey vierendeels have similar stresses and could be made geometrically identical from the same standard pieces. This gives simplicity and economy compared to a traditional high-rise, where stability and vertical load structures increase in size from top to bottom. Vierendeels were sub-divided into factory-welded cruciform components to suit transportation and site assembly. Site joints are at points of minimum bending - approximately the same locations under both wind and gravity loads (Figs 13-15).

The ends of the vierendeel frames are squashed by the axial shortening of the supporting main core columns which are heavily stressed in compression (Fig 16). This gradually increases as the core columns rise above the vierendeel and take load from the upper part of the tower. The effect is increased by shrinkage and creep of the concrete casing to the core columns, and is particularly significant at the bottom of the tower. At these localised highly stressed locations, steel of grade StE460 was provided to give higher strength without changing size, which would generate additional stiffness and attract additional forces.



16. Squashing of the vierendeel.

Vierendeel link frames

Link frames connect the pairs of core columns across the building's rounded corners, passing between the lift shafts. These - formed of 1m deep vertical members and 1.1m deep beams, both 300mm wide - are similarly standardised throughout the building. The efficiency of the vierendeel link frames was optimised like the main vierendeels.

Main core columns

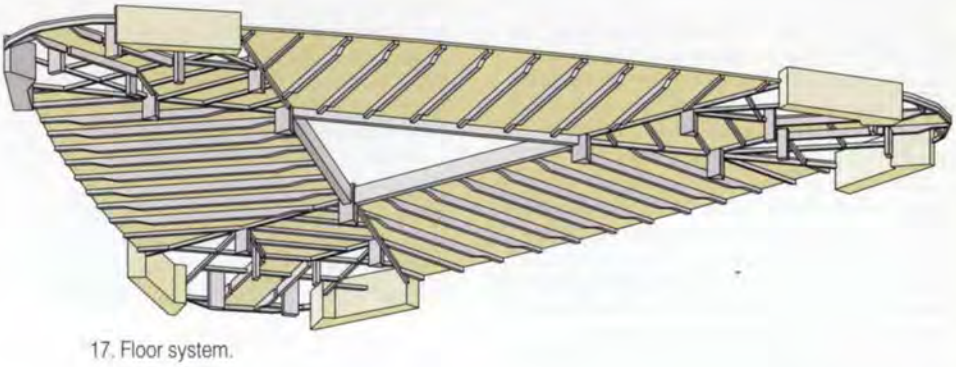
The three pairs of main composite columns at the ends of the vierendeels - around 7.5m long by 1.2m wide - are made from two internal H-section plate steel columns linked by bracing and beams and encased in reinforced concrete. Again, the steel columns are standardised, of the same size and weight from top to bottom. The concrete cross-section is constant throughout, but to carry the increasing mass of the tower, reinforcement content and concrete strength are increased to heavily reinforced Grade 55 concrete at entrance level.

The core columns perform several functions:

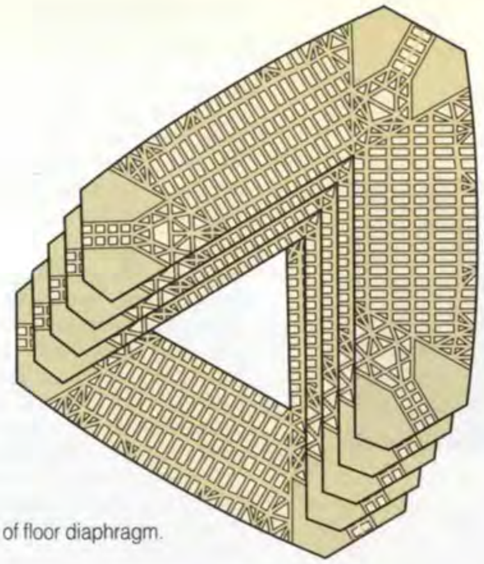
- The composite section is an efficient and economic structural element, carrying ultimate axial loads of 175 000kN and shear forces of up to 11 000kN. Bending is generally modest except at the entrance level where there are no vierendeels and the core columns act alone as portalised bending elements.
- The steel core of the column acted as a geometrically repetitive construction jig to simplify erection, allowing early steelwork erection ahead of concrete encasement.
- The steel vierendeel to steel core column connection gives a reliable load transfer system from the vierendeel into the core columns. Shear connectors transfer the forces into the concrete.
- The concrete encasement provides damping, reducing sway accelerations of the very light building under wind, and improving the comfort of the occupants.

Floor system

The office floor structure is of conventional composite steel beam / concrete slab construction, chosen for long column-free spans with minimum depth (Fig 17). Steel beams 560mm deep at 3m centres span 15.65m across the office and garden floors. For primary horizontal service distribution, the beams are notched to 260mm deep at each end and have multiple service penetrations. By integrating services distribution within the beam zone the floor-to-floor height was kept to 3.75m, very low for a long-span floor structure and including a 125mm raised access floor and 2.75m ceiling height. The garden floors are similar to the office floors, but designed to carry local landscaping loads up to 13kN/m^2.



17. Floor system.



18. Finite element model of floor diaphragm.

Each floor acts as a horizontal diaphragm to maintain the plan shape, restrain the columns laterally, and distribute in-plane stability forces to the perimeter tube structure. Every four floors a full diaphragm links all sides of the tube, providing a simple check on dimensional control during construction. These floors also resist the curved vierendeels' tendency to tip, typically dealing with in-plane forces from the top of one (which tries to tip out) and from the bottom of another (which pushes in). The diaphragm system was designed to share the large in-plane forces arising from this around the perimeter tube. In the core areas, the floors are weakened by ducts, stairs and lift shafts; here a flat triangulated grid of beams carries the in-plane forces.

The in-plane behaviour of the floors was analysed using GSA finite elements (Fig.18).

Two models were studied:

- Full diaphragm (three-petal) at every fourth level (garden floors)
- Partial diaphragm (two-petal) at typical office floors.

The models assessed the effects of:

- *Forces from the perimeter stability tube and cladding:* In the 3-D analysis of the perimeter tube, the floor diaphragm was modelled as a stiff ring, so more detailed study of the in-plane forces induced in the internal beams and slabs was needed.
- *Column restraint forces:* As in-plane stiffness of the floor plate affects column buckling behaviour, the principal diaphragm stiffnesses at each column were found for subsequent use in the buckling analysis.

Arups' BUCKLE program provided column restraint loads required from the diaphragm. The maximum beam forces were generated by columns in each core rotating about the point of intersection of the major axes of the concrete core columns.

The office floor slab is 130mm thick and was cast onto profiled metal deck formwork spanning between the beams, without temporary propping, saving labour and site time. The floor deck has to resist stresses from vertical loads and from its diaphragm behaviour. The most onerous combinations of these were used for slab reinforcement. Floor beams were designed using Arups' program COMPOS, amended to comply with German regulations. Axial loads up to 600kN generated from the floor diaphragm behaviour were included. Finite element floor beam models, developed in parallel using GSA, checked strength and overall behaviour, particularly round the many large web penetrations.

The composite floor structure is shallow, with low mass and comparatively low damping in the open plan areas; typical long-span office floor beams have an estimated natural frequency of vibration of 3.5Hz. The long-span garden floor beams have a frequency of 2.75Hz, but a much larger mass. The dynamic performance under footfall vibration has an acceptable response factor (R) between 4 and 8, in line with Steel Construction Institute (UK) guidelines.

Atrium edge beam system

Spanning 18m to carry the inner edge of each floor petal between the atrium corner columns, these beams have a load-sharing system to link the deformations of all beams in the 'village' groups; this reduced their required depth from 1.5m to 1.1m, and dramatically lessened movement joint requirements for the internal façade system between floors.

Internal columns

These carry large gravity loads in two areas. A single triangular steel column at each corner of the atrium varies from 1.4m wide at the base to 600m at the top, its plates up to 150mm thick. In the core areas, smaller columns help frame around openings; these are generally steel I-sections except at the base where space restrictions necessitated rectangular box sections.

Buckling behaviour of the internal columns was assessed to find their effective lengths, and restraint forces for diaphragm analysis. In many cases the former exceeded one storey; the core area columns at the base exceed three storeys.

Secondary structures

Plant tower and mast

Above the highest office floor is a triangular plant tower and mast structure 77.5m high. This is in tubular steel, conventionally braced, and carefully detailed to avoid corrosion and fatigue problems in an exposed position where maintenance is difficult.

Atrium dividing screens

At the top of each 12-storey village is a 15m equilateral triangular glazed steel structure (Fig 19), spanning the atrium, which must maintain integrity for 30 minutes in a fire. It is a triangular grid of pairs of 200mm x 25mm plates, with secondary 120mm deep break-pressed V-beams.

Sky garden glazed wall

This has a bow-string mullion system 14m high, 3° off vertical to control radar reflections. Lateral torsional buckling is prevented by building the mullions in pairs, with rigidly jointed transoms.

Fire resistance

The structure generally is rated at F120. The steelwork has boarded or sprayed fireproofing.

Steel quantities

Including connections, the building contains c18 700 tonnes of steel, or about 200kg/m^2 of built superstructure area, apportioned as follows:

	tonnes	*kg/m^2*
Columns:	5800	62
Vierendeel frames:	4900	52
Link frames:	1600	17
Floor beams:	5800	62
Secondary structures:	600	7

It's worth noting that if the results of the wind tunnel tests had been allowed (see above), there would have been only 15 900 tonnes (170kg/m^2) - very efficient for a building with so many large openings and long spans, and comparing favourably with more conventional similar-sized high-rises.

19. View up the atrium showing dividing screens.

Substructure and foundations

'A vast, unbottom'd, boundless pit...'(Burns)

The foundations were one of the most complex and sensitive aspects of the structural design: a particular challenge due to the heavy and concentrated loading configuration of the new tower, the presence of the nearby existing 32-storey Commerzbank HQ, and the physical and geometrical constraints of the site.

The Arup/KuK joint venture designed the foundation structure. The geotechnical consultant *Ingenieursozietät* Katzenbach und Quick appraised the site geology, advised on foundation type, did the site investigation, and reported on the foundation soil, including settlement analyses.

The foundation was designed to give:

- economic viability of permanent and temporary works
- long-term serviceability of the new tower, and new perimeter buildings
- unimpaired serviceability of the existing tower and nearby buildings, roads, and services
- a realistic site programme.

Site constraints

Stratum	*Depth to top of stratum (m)*	*Stratum thickness (m)*
Fill	0	2 - 6
Sand / gravel	2 - 6	2 - 7
Frankfurt Clay	5 - 9	29 - 35
Inflata strata	38 - 44	c20
Cerithien strata	c60	c40

The groundwater table lies approximately 5.5m below existing ground level, with a projected possible rise of 1.2m over the design life of the building. Existing buildings including the older Commerzbank tower are retained on the south-west third of the site. The mean effective stress in the Frankfurt Clay under the raft of the old tower is about 300kN/m^2. At its edges this raft is only 9.3m below existing ground level and extends almost to the face of the new tower. Also, there was little room for the latter's foundation to project beyond its superstructure footprint on the west and north site boundaries.

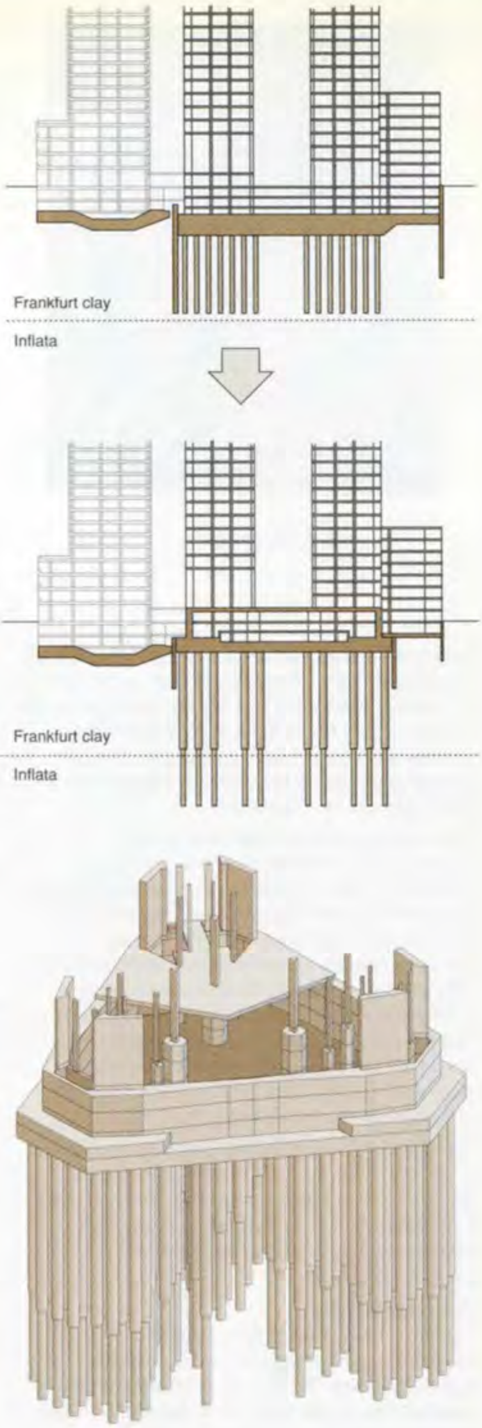
The mean settlement of the older Commerzbank tower was c130mm, measured some three years after completion in January 1975. Given the proximity of the old and new buildings, and the proven compressible nature of the Frankfurt Clay, the major influences on developing the foundation design were keeping the existing buildings stable and preventing movements that would impair their serviceability.

Loading configuration

The building is unusual in the way it bears on its foundations. All the 132 000 tonne superstructure load concentrates into the three corner core areas, as follows:

Element	*Proportion of load carried*
Corner core columns	59%
Link frame columns	6%
Atrium corner columns	17%
Other internal columns	18%
Total	100%

As well as gravity loads, wind load passes to the foundation in a combination of axial and bending components via the columns of the external stability tube. Superstructure loads would generate an effective stress at foundation level of c1750kN/m^2 if applied solely over the 250m^2 of each core footprint. Over the whole tower footprint of about 2150m^2, the superstructure loads generate a mean effective stress of c550kN/m^2 - too high for simple raft foundations because of excessive settlements. An early concept was to combine a raft and settlement-reducing piles - successfully used for other Frankfurt office towers. The economic feasibility of up to four basement storeys under the tower, with three elsewhere, was also looked at. But further knowledge of the site showed that without extensive and uneconomic temporary works, building such a deep basement would endanger the existing tower. However, as the new building's mass would effectively replace that of soil excavated, the deep basement would only cause a small net change in effective stress on the foundation soil, giving correspondingly small settlements in the final condition. Conversely, shallower basements would have the benefit of significantly less complex temporary works but, with less excavation, the mass of the new HQ would significantly exceed the small soil mass removed, giving unacceptably large settlements from the large change in effective stress in the foundation soils.



20. Evolution of foundation design.

The piled foundation

After long discussions with Katzenbach und Quick, and advice from the approving authority, a piled foundation 45m down into the Inflata strata, with shallower basements, was determined as giving the best balance of cost economy, construction programme, and performance (Fig 20). Such deep piling had never been used for a Frankfurt high rise before; experience of piling in the Inflata and Cerithien strata around the city was limited to the Flößerbrücke across the River Main.

Developing this theoretical solution into built reality meant extrapolating existing experience, and close iterative design development between the structural and geotechnical teams and piling specialists. The final project has 111 large diameter, bored, cast in situ concrete piles, distributed under the three core areas.

They transmit the concentrated loads directly into the Inflata strata and are grouped as directly as possible under the load to minimise load transfer across the pile cap.

21. Typical pile.

They are typically 45m long, constructed using full length temporary casings to maintain bore stability during excavation (Fig 21). At 25m depth the width reduces from 1.8m to 1.5m to allow a second, smaller-diameter temporary casing for the lower part to be placed. This avoids the friction from a full-length, single-size casing.

Individual pile working loads are typically 14-30MN. Axial shortening of the pile (due to elastic behaviour, creep and shrinkage) mobilises some 8MN of shaft friction in the Frankfurt Clay, the remainder carried by the Inflata strata. The piles operate primarily as rock sockets in the Inflata layers. A geotechnical factor of safety of 1.75 was adopted, justified by a series of small diameter pull-out tests. Due to its variability, the Inflata strata around the toe of the piles was shaft and base-grouted to fill any local voids and homogenise its mechanical properties.

The predicted overall settlement of the foundation is 60-70mm, of which c20% comes from axial shortening of the piles under load. This is about half that measured at the existing Commerzbank tower, a building less than half the size but roughly equal in weight.

The substructure

This large three-level cellular structure, housing plant and services, transfers loads from the superstructure to the foundation and supplies effective fixity to the columns of the stability tube, as well as keeping groundwater out of its functional spaces. It is a truncated triangular box, of cast in situ reinforced concrete (Grade B45), with two basement storeys below ground level and one above supporting the Plaza slab. Its four elements are:

- 4.45m thick pilecap zones below the tower superstructure core areas
- 2.5m thick base slab under the remainder of the tower
- 12.35m deep side walls, typically up to 3.5m thick, along the sides of the tower footprint
- 0.75m deep top Plaza slab.

The formation level of the core pilecaps and the base slab is c9m below existing ground level, just above that of the adjacent existing tower raft. The pilecap under the tower cores disperses the intense local column loads to the nearby pile groups. Away from the cores, the 2.5m thick slab resists hydrostatic groundwater uplift and the upward pressure from the upper surface of the Frankfurt Clay generated by clay heave and overall building settlement. The thick sidewalls have several openings for doors and service routes, their location carefully chosen to preserve the substructure's integrity.

The Plaza slab laterally restrains the superstructure columns, contributes to the fixity of the columns of the stability tube, and supports the Plaza and entrance lobby. The tower superstructure columns bed into the concrete elements of the substructure for continuity.

The tower substructure is structurally isolated from the substructures of the perimeter buildings.

Perimeter buildings and car park

The neighbourhood scale and visual harmony between tower and city were preserved by rebuilding and restoring the buildings on the perimeter street frontages, and by opening up the city block containing the tower with new public spaces at Plaza level, a winter garden housing restaurants, and cafes and space for performances and art exhibitions. The varying geometry of the perimeter buildings and the precise geometry of the tower were then reconciled by glazing over the public space.

The new perimeter buildings are a mix of apartments, shops, branch bank and car parking as well as a new auditorium. Below ground, these areas house services plant. The many different functions require a variety of column grids - maximum spans 17m over the loading bay; more general spans of 8m x 10m in the car park. All the structures are cast in situ concrete with beams and slabs, or flat slabs, and stabilised by a mix of shear walls and frame action.

The structural aim was to respond to the differing needs, but find solutions minimising the need for transfer structures.

As much parking as possible is provided in the limited space, partly under the tower and partly within the perimeter buildings, in a continuously warped, helical slab. All ramps having parking bays each side, optimising the use of space.

The perimeter buildings are much lighter than the new tower, and generally have one basement level. Given the relatively small effective stress changes, they are supported on raft foundations in the sands/gravel above the Frankfurt Clay. Any existing foundations or disused basements were backfilled to create the necessary foundation level.

Proof engineering

'... beholding heaven, and feeling hell...'
(Thomas Moore)

In Germany, the task of checking structural designs is formally granted to the *Prüfinginieur* appointed by the local authority. This check is demanding and meticulous, and is a requirement for construction to proceed.

After scheme design was completed in August 1992, the London Arup/KuK team expanded for the submission of a co-ordinated structural design and co-ordinated architectural drawings to König und Heunisch, the chosen *Prüfinginieur*. Following planning application to the City of Frankfurt on 17 December 1992, a series of structural submissions at roughly six-week intervals were agreed with the *Prüfinginieur*. These were driven by the need to obtain the Construction Permit on 1 October 1993 and delivery was a contractual obligation for the team. After approving and checking each submission, the *Prüfinginieur* wrote to the City to support release of the Construction Permit.

Around Christmas 1992, the Foster team moved to Frankfurt, and Arups also established a local project office to assist design development and co-ordinate with the *Prüfinginieur*, with London completing production documentation. The project office remained open for around a year, and throughout this time the *Prüfinginieur* was kept fully aware of progress of the structural design and its philosophy, particularly in critical areas like tower foundation and superstructure design. This helped ensure relatively smooth and successful checking when packages were formally issued.

Arup/KuK achieved every submission on time. In total, some 36 lever-arch files of calculations and drawings were approved, representing 65 man-years of structural design effort.

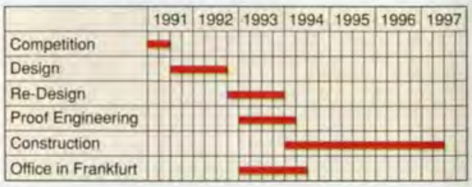
23.

These submissions imposed a rigour that galvanised the whole design team. In effect, the *Prüfinginieur* checking reports became the critical path for the entire design, the milestones around which progress was focussed.

Design management

At an early stage the architect appointed Arup Project Management for the overall master programming, construction planning, and planning and sequencing demolition and enabling works. Within the master programme (Fig 24), a detailed programme was developed with the designers, incorporating key client decisions. The licences needed for work to start were the demolition permit and the appropriate building permit. APM established the permits' content, ensured that client and designers knew what was needed and delivered their input, and liaised with the City of Frankfurt on submission timing. APM monitored and reported progress against the design programmes and client decision schedules throughout preconstruction. Under this strict design management regime, the team delivered the tender documentation and achieved both the demolition and building permits on programme.

24. Master programme.



Achieving the first of the seven submissions was tight, but once the documents were loaded into the back of a very fast German car.....

....two Arup engineers drove from London to Frankfurt through the night and delivered the package with at least 10 minutes to spare.

22.

Construction

The main contractor, Hochtief AG, started on site in May 1994, the top of the antenna was completed in October 1996, and the fitted-out building was handed over in May 1997. The overall sequence was site demolition, foundation, basement, and tower construction. Perimeter building construction was programmed to take place later to maximise use of the site for access to the tower, and also to minimise relative settlements between the tower and perimeter buildings.

Foundations and basements

After demolition, the foundations to the perimeter buildings were constructed above the water table within the existing retaining walls, which were temporarily propped. Soil strata were heavily surcharged to safeguard the stability of the existing tower and its foundation by minimising short-term effective stress changes in the soil. Under the new tower, the deep basement lies below existing water table level. A continuous secant pile wall was installed to form a 'cut-off' around the area, maintaining groundwater levels outside the excavation and allow safe de-watering, piling, and excavation within.

The tower

Major steelwork components were factory welded and fabricated, and delivered at night when the streets around were quiet. The 'construction-kit' approach paid handsome dividends, as the contractor could erect the superstructure at least two floors per week (Figs 25-27), using three tower cranes. All main frame site connections were friction-grip bolted for simplicity, ease of fit, and reliability.

Significant temporary works to the tower were required to:

- support new vierendeels from completed ones below
- brace erected levels of steelwork vertically and horizontally until the floor diaphragm structure was complete
- aid concrete encasement of the core columns from climbing formwork following closely behind the structural steel erection.

26. Construction of first vierendeel showing temporary props.

25. First lift of floor column steelwork.

27. Construction at April 1996.

Conclusion

'..for which of you, intending to build a tower, sitteth not down first, and counteth the cost, whether he have sufficient to finish it...' (Bible, Luke 28)

The new HQ has a total gross area of about 120 400m², of which 85 700m² is in the tower, 12 700m² in the basement and the balance in the perimeter buildings and public plaza.

The cost has not yet been published, but the building has been finished. In the rarified atmosphere of high-rise building design, the new Commerzbank HQ is unique. It breaks down the enormous bulk of a skyscraper so that its users can share the experience of being there. It defers harmoniously to the fabric of the city. It is a holistic design driven by sound development economics incorporating an innovative structure and a naturally-lit, naturally-ventilated interior.

A trip beneath and up through the building is a memorable experience. It remains to be seen how it foreshadows high-rise buildings of the future, as workplace expectations and political pressures rise.

Realising the building, fully tested the commitment of the whole design team. As well as the considerable technical challenges, there were numerous hurdles due to the tight programme and budget, incompatible appointments ending at different project stages, partial re-location to Frankfurt, geography, language, different cultures, different methods of working and many domestic upheavals.

In meeting these challenges, the team of more than 150 designers, including up to 50 from Arups and KuK, completed their appointed tasks on time and within budget.

A major driving force behind this achievement was the sense of common pride and purpose, the shared sense of adventure, and the mutual commitment the design inspired within the team. It helped to have a sense of humour.

Acknowledgements

'... the deed is outdone by the doing...' (R. Realf)

The authors would like to thank their team of engineers in London and Frankfurt for their dedication and commitment throughout the project. Without their efforts, the building would not exist.

The entire Arup/KuK team gratefully acknowledges the tremendous support of friends and families, who endured, shared and helped to release much of the pressure of the project. We also thank the Commerzbank for its brief, the design team for its response, and the *Prüfinginieur* for his diligence.

Credits

Client:
Commerzbank, Frankfurt

Architect:
Sir Norman Foster & Partners

Structural, traffic, fire, wind, and geotechnical engineers, and design managers:
Ove Arup & Partners Andrew Allsop, Daniel Backhauser, Peter Bailey, Chris Barber, Trevor Baker, Ian Barnett, Claudia Berger, Harry Bridges , Andrew Chan , David Clare, Eleanor Clark, Chris Clifford, Ken Coffin, Paul Cross, Pat Dallard, Adrian Falconer, Karl Fitzgerald, Kevin Franklin, Jim Fraser, Jenny Greaves, John Jo Hammill, Julian Hill, Yasunari Hino, Berthold Keck, Rachel Kelly, Ruth Lees, Mike Lewin, Minh Lou, Martin Manning, Tim McCaul, Gabriele Del Mese, Hugh Morrison, Uli Mutter, Arata Oguri, Peter-Platt Higgins, Klaus Reußner, Steve Roberts, Tim Roe, Rolf Schürmann, Brian Simpson, Chris Smith, Tony Stevens, Franz Stranski, Deb Thomas, Andrew Tompson, Paul Tonkin, Mark Trueman, Alan Tweedie, Jean-Paul Velon, David Vesey, Paula Walsh, Seán Walsh, Ian Wattridge, Chris Wise, Ray Young, Jack Zunz.

Associate structural engineer:
Krebs und Kiefer

Geotechnical consultant:
ISKQ

Environmental engineer:
Roger Preston & Partners, with Petersen & Ahrends

Electrical engineers:
Schad & Holzel

Cost consultant:
Davis Langdon & Everest

Wind tunnel test laboratory:
RWDI

Prüfinginieur:
König & Heunisch

Project manager:
Weidlplan

Space planning:

Quickborner Team

General contractor:
Hochtief AG

Piling contractor:
Gründ & Pfahlbau

Structural steel contractor:
DSD Dillinger Stahlbau

Illustrations:
1, 5, 19, 27, 28: Ian Lambot
2, 21, 22: Ove Arup & Partners
3, 4, 6-8, 10-13, 16-18, 20, 24: Nigel Whale
9: Andrew Allsop
14, 15: Chris Wise
23: Seán Walsh
25, 26: Sir Norman Foster & Partners

28. A sky garden in June 1997.

IT for Scottish Equitable HQ, Edinburgh

Daniel Grimwade

Arup Communications was invited by Scottish Equitable in September 1992 to join the design team for their new head office project; Scottish Equitable is a leading life insurance and pensions company, and now part of the international Aegon Group, with 33 branches throughout the UK. Their new three-storey, 30 000m^2 HQ is based in the Edinburgh Business Park, on the outskirts of the city, and houses up to 2000 staff. Arups advised on every issue relating to IT and communications in the project, which divided into six main areas:

- advising the design team on communications and IT issues relating to the building itself
- designing the cabling system
- assisting Scottish Equitable in the choice of a new telephone system
- advising on the data network design
- guiding and assisting the client through all the issues involved in ensuring a successful move into the new headquarters
- advising and assisting Scottish Equitable in setting up the necessary procedures to continue managing the communication systems.

Building issues

Careful planning is needed to allow users to communicate effectively and use IT equipment from their desks. With this in mind, Arup Communications compiled a report for the other members of the design team, summarising the IT requirements and addressing questions including:

- *Was the proposed site on the west side of Edinburgh too close to the Airport, from which interference might be experienced?*

Following tests, it was concluded that Edinburgh Park was a safe location for the hub of Scottish Equitable's IT network and business to be located.

- *Where should the central communications and IT equipment be housed, and would this equipment require additional building facilities?*

This resulted in the creation of a data centre comprising a complete wing of the ground floor. Within this section of the building are rooms for the mainframe and its associated equipment, the telephone system (PABX) and other voice equipment, the investment managers' servers, and the network services incoming termination equipment. From a building services point of view, this part of the building has been treated separately from the remainder. It has its own resilient power supplies, transformers and chillers. The raised floor is much deeper (850mm) to allow underfloor air distribution. The data centre is protected by UPS, and the two central computer rooms have a very early smoke detector alarm (VESDA) system.

- *How should the network services enter the site and the building and connect to the data centre?*

Communications ducts were laid from the edge of the site directly into the building by two different routes. At the edge of the building, cable jointing rooms allow the external cables to be connected onto internal cables. These, in turn are connected through the building to the data centre where the termination equipment is housed. A third duct route for disaster recovery allows connections to be made to a temporary mainframe located in the contractor's car park.

2. Site plan, showing ducts and cable entry.

- *How should voice and data communication services be connected from the data centre to the work space?*

All the services connect together via cabling, but it must have space to run and rooms to terminate in. Throughout the office areas there is a raised floor allowing both communications cabling and small power to be distributed within the open plan areas. The building, for the most part, has three floors and each of these has four Sub Equipment Rooms (SERs) allowing for the termination of cabling and housing of network equipment. Running vertically between the SERs are communications risers for connection between the data centre and SERs.

Cabling

A good cabling design must consider the services it supports: the quantity required within a given area, and flexibility to accommodate future changes and growth. In Scottish Equitable's new HQ - and indeed most modern buildings - the cabling divides into two categories: primary cabling connects the central services rooms within the data centre to the SERs; secondary cabling connects the SERs to the floors and desks.

Three types of primary cabling have been installed at Scottish Equitable. For voice services, multicore cable connects the SERs to the PABX rooms, whilst for data services there are fibre optic and UTP copper cables. The vast majority of secondary cabling is category 5 UTP which can be used for a wide range of functions simply by placing adapters on the end of the cables. This cabling enables data to be transmitted up to speeds of 100Mbs, and is used for digital and analogue telephones, fax machines, token ring data connections and IBM 3270 VDU traffic. In addition to the category 5 cabling, a few coaxial cables have been installed to provide TV aerial points in meeting rooms and some office areas.

Neatly and effectively interfacing the cabling to the desks, whilst retaining flexibility for future expansion and changes, can be very difficult. In Arups' design - affectionately known as the 'grid and grommet' - the communications outlets are installed in a grid, with six outlets terminating every 3m on the concrete slab below the raised floor. To allow the services to be connected to the desks themselves, holes have been made in the raised floor and fitted with grommets located to suit the furniture layout.

1. Scottish Equitable from the air.

Drop leads run from the grid outlet points and up through the grommet into the desk cable management system. This solution has ultimate flexibility: the quantity of drop leads installed can be varied according to need, grommets can easily be moved simply by lifting the raised floor, and using a single cable type allows any cable to be used for a range of communications services.

Voice systems

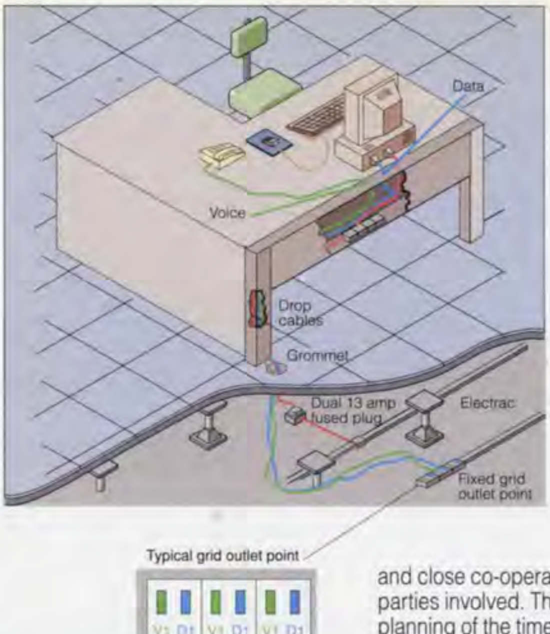
Arup Communications compiled a specification of all the requirements of the new telephone system (PABX) Scottish Equitable wished to purchase. The system was not only to provide basic telephone functions for desk-based staff, but also modern digital handsets for the investment department and call centre functions for the customer help desk.

The most testing requirement was that the system had to be housed in two separate rooms for resilience purposes while functioning as a single unit from the users' perspective.

The chosen system is the Ericsson MD110 whose modular design meets these requirements. In one room all the odd extension numbers are supported and in the other room all the even numbers, thus ensuring that if one room should fail, only half the users would lose service and they would be spread evenly throughout the building.

Data systems

Scottish Equitable wanted to unify their approach to data networking and install a more comprehensive network design. They had already commenced installing Madge Token ring equipment as the majority of their staff moved from using VDUs onto PCs. While much of the detailed design work was done by Madge themselves, Arups ensured that their suggestions were reasonable and met the design requirements. Central to the design of the network are the ring switches which connect the user rings together and connect them to the service rings, to which all the servers and gateways are attached.



4. Left: Typical desk installation. 5. Typical office interior.

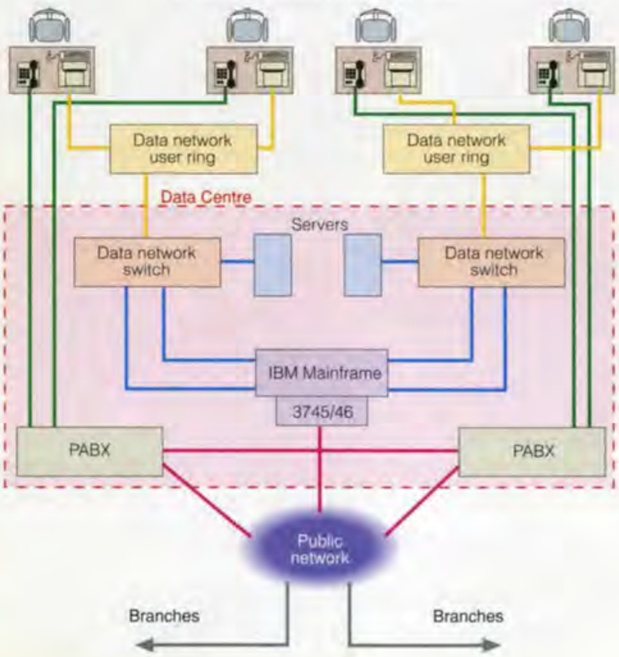
The ring switches and service rings are housed within the two computer rooms, and the user rings are housed in the SERs with connections between the rooms made via fibre optic cabling. The system was designed with a high level of resilience to ensure there is no single point of failure.

While the decision as to exactly which mainframe should be purchased was made by Scottish Equitable, Arups assisted in designing the layout of the computer rooms, and the specification of the inter-connecting cabling. Scottish Equitable continue to use about 400 VDUs and these connect to the mainframe via 3299 splitters and 3174 controllers. Arups advised on the best connectivity mode, and use of structured cabling.

Move

Throughout the project's three-year lifespan, Arups' attention was always focused on the end user. To successfully achieve a good cut-over of some 1500 staff and more than 4000 pieces of equipment involves a lot of careful planning and close co-operation by all the parties involved. The physical planning of the timetable for the move and sequence of events fell to the move consultants (RIS). It was Arups' job to ensure that all the communications and IT issues were suitably addressed, to ensure smooth cut-over weekends.

3. Voice and data information flow.



For several months leading up to the first move, Arups chaired meetings between the client and construction managers to ensure that issues were being addressed and that areas within the building were in a suitably clean state to allow installation of the PABX, mainframe, and IT network equipment well ahead of staff occupation.

As staff were being moved into the new building over a series of cut-over weekends, it was necessary to plan how those within the new head office would communicate with their colleagues in the old premises in the centre of Edinburgh. Temporary links were installed between the sites for both voice and data traffic, allowing the mainframe to be moved out to Edinburgh Park first and for users to continue to log in from the city centre offices. For voice traffic, the temporary links allowed for a centralised operator covering the three sites, as well as a seamless operation between the offices, by using a complicated series of diverts and translation tables.

The largest operation led by Arups was managing the cabling system to ensure that the correct services were provided to the right desk. This was complicated by the shear quantity of changes to extension numbers and the locations of equipment right up to and through the move period. So a large database was managed and maintained, containing details of all work spaces, cables, people, equipment, and how they related. Arups managed the database, and the cabling contractor made the changes to the cabling connections (patching and jumpering) as per instructions.

Whilst the move weekends were extremely busy and at times tense, as people got tired from continuous working, the moves passed off without any serious holdups.

Post-occupation

Now all the staff are in and working, the job is for the most part complete. However, the team was careful not to leave the client too quickly, as purpose-designed and built offices require sensible management, and Scottish Equitable was keen to involve Arups in that process. This in turn led to new opportunities for design work. Since occupation Arup Communications has helped Scottish Equitable set up moves and changes procedures, appoint a cable management contractor, design audio visual systems for the conference room, with acoustic design for the Activity Centre (Arup Acoustics), and with specialist lighting systems for the executive suite (OAP Edinburgh).

Conclusion

The multiplicities of this project made it very interesting, particularly with the client allowing Arups freedom to comment on all the IT aspects of the project. The client has now been in the building for a year, and the design and the advice given has proven to be robust and appropriate.

Credits

Client:
Scottish Equitable plc

Construction managers:
Lehrer McGovern International

Design architect:
Koetter Kim and Associates

Architect:
Adamson Associates

Structural engineers:
Thorburn

Mechanical & electrical engineers:
Roger Preston & Partners

Communications consultants:
Arup Communications
Bill Southwood, Peter Keogh, Gordon Lland, Daniel Koopman, Daniel Grimwade

Move consultants:
Relocation Information Systems (RIS)

Suppliers:
PABX: Ericsson
Data network: Madge
Cabling: Honeywell

Illustrations:
1. Guthrie Photography
2: Emine Tolga
3, 4: Jon Carver
5: Peter Mackinven

Hulme Arch Bridge

1. Computer-generated competition image

Naeem Hussain
Roger Milburn
Ian Wilson

Introduction

In 1992 the Hulme City Challenge was launched with the aim of regenerating this area of southern Manchester, which had become associated with poor housing and limited opportunities. The vision was to establish a high quality urban environment with a wide range of housing, employment and leisure opportunities. A project for a landmark bridge was commissioned by Hulme Regeneration Ltd in association with Manchester City Council, who identified the need to reinstate Stretford Road. This formerly important east-west route had been bisected by the dual north-south carriageways of the arterial Princess Road, and this was thought to have contributed to Hulme's isolation and dereliction. In reopening the route, the promoters wished to create a landmark centrepiece to act as a visual marker of Hulme's regeneration.

A two-stage open design competition was held; from the first stage in March 1995 six teams were chosen to develop their schemes further, and in June that year the Chris Wilkinson Architects/Ove Arup & Partners design was chosen.

Design concept

It is both simple and unique. The bridge is supported by cables hung from a single diagonal parabolic arch, the placing of which allows it to appear as a gateway both to motorists on Princess Road below and to users of Stretford Road as it crosses on the new bridge itself above. The arch rises 25m above the bridge deck, and was conceived as a bright, smooth, metallic structure, an effect achieved by using a plated steel box section coated with bright aluminium paint.

The arch section is trapezoidal throughout and varies from 3m wide and 0.7m deep at the crown to 1.6m wide and 1.5m deep at its springings. This variation, combined with the essential asymmetry of the bridge as a whole, creates a live structure which is perceived as different from each new viewpoint. It also provides the interest of a constantly changing form for observers passing through it.

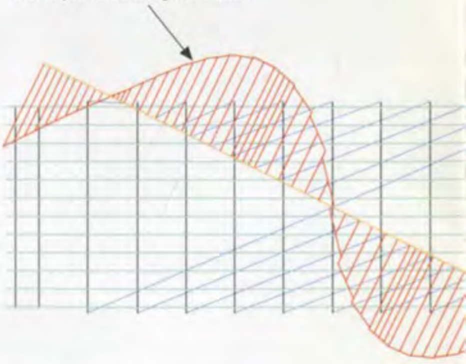
2. The completed bridge.

Structure

The arch is attached to very substantial ground-bearing concrete foundation blocks (8.5m x 6.5m x 5.5m) at each springing. Both connections are made with 32 high tensile stainless steel bars, each 40mm in diameter, anchored deep within the foundation and designed to ensure that no tension results at the interface between the steel and the concrete under any service load condition after being stressed.

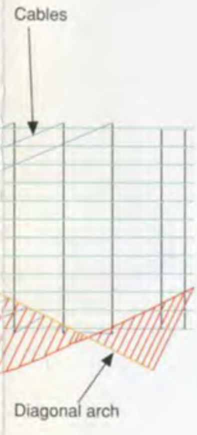
The arch shape follows the thrust line generated by the in-plane effects of permanent load from the cables reasonably well. However, due to the arrangement of the cables, the arch is subjected to very considerable out-of-plane asymmetric bending effects (Fig 3). These governed the design, in some cases utilising up to 75% of the section capacity, and as a result the arch functions more as a laterally-loaded bending member than a conventional arch.

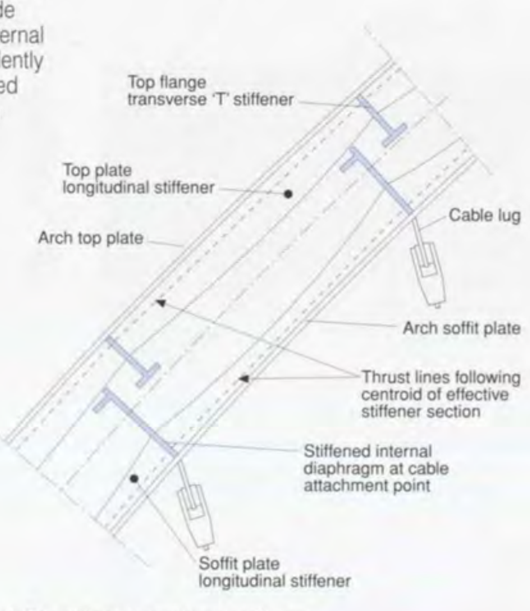
The arch top and soffit plates have curved stiffeners, shaped so that the centroid of the effective section (ie the stiffener combined with the relevant effective width of top or soffit plate) follows a straight line between the diaphragms at cable connection points (Fig 4). This means that the faceted thrust line follows the section centroid and only minimal bending effects result.



3. Arch bending moments.

The arch section was designed to be fabricated in two pieces like a coffin. The soffit and two side plates with the cable lugs and associated internal diaphragms form the 'box' and the independently stiffened top plate becomes the lid, connected to the box with an external longitudinal seam weld on each side.





4. Thrust lines through arch stiffeners.

At the crown of the arch, where the curvature is more pronounced and the section shallower, the size, number, and complexity of stiffeners required would have given a very complicated and costly fabrication, so to avoid this it was decided to fill this section of the arch with concrete and stiffen the plates by means of long shear studs embedded in the concrete. A lightweight concrete fill was used to minimise load in the structure and a high flow mix specified to ensure that no voids would remain. The section was stiffened to avoid bulging under the hydrostatic head of the concrete.

The bridge deck

The 52m span bridge deck is hung from the arch by 22 spiral-strand diagonal cables, 51mm in diameter, each with a minimum breaking load of 216 tonnes. They have pinned open sockets where they connect to lugs attached to the arch soffit, and externally threaded cylindrical sockets to allow adjustment at deck level. The cables are asymmetrically arranged and fan out in opposing directions with each side of the deck connected to a different half of the arch. The resulting arrangement encloses the space over the bridge and contributes to the visual interest of the structure as a whole.

The bridge deck is a composite concrete slab laid over 17 transverse girders spanning on either side to two steel edge beams connected to the stay cables via outrigger brackets. The edge of the structure is given visual continuity by a tubular steel nosing supported outside the cable brackets.

The deck is locally supported on two simple piled abutments at each end. Vertical support bearings are provided at the four corners of the deck with longitudinal restraint supplied at one end and expansion allowed at the other. In the middle of the two end girders a transverse guide bearing locates the deck laterally as well as resisting the tendency of the bridge to rotate on plan because of the arrangement of the cables.

Bollards along the inside of the footways on either side of the deck stop high-sided vehicles riding up onto the footways and snagging on the inclined cables.

Construction

Princess Road
CLOSED HERE
From 7pm Fri 25th Oct
to 6am Mon 28th oct
Use alternative Routes

Princess Road links Manchester Airport to the city centre, and at the site its dual two-lane carriageways are separated by an unusually wide central reservation. The structure was designed for extensive off-site prefabrication with intensive construction efforts coinciding with possessions of Princess Road, the number of which were limited in the contract.

The foundations under each arch springing contain 270m³ of 50N/mm² concrete. To limit cracking it was a requirement that the maximum temperature in these be limited to 70°C, with the maximum differential temperature not exceeding 20°C. The maximum temperature was controlled by the mix design, which included 75% cement replacement in the form of ground granulated blast-furnace slag; the maximum differential was achieved by insulating the extremities of the pour. Thermocouples were placed at key locations in both pours and readings taken over 10 weeks. The maximum temperature recorded was 69.9°C after about four days and after the 10 weeks the middle of the pours had cooled to some 35°C.

5. The deck being placed.

The high tensile bars were held in place by a steel framework cast into the foundation, its top and bottom plates drilled simultaneously with the arch baseplate to ensure a matching alignment. Three tapered dowels were attached to the top plate to help position the arch.

Both the arch and the deck were installed during single week-end possessions. The deck was prefabricated as individual beams before being brought to site and assembled into three 17m x 17m sections in the wide central reservation. These were then craned into position on four temporary trestles in the reservation. During the same possession Omnia permanent formwork panels were loaded onto the deck in the areas over Princess Road after the deck longitudinal edge beams had been made continuous.

The arch was fabricated in six pieces approximately 15m long and then welded together in the central reservation into two 80 tonne halves. These halves were installed by two 500 tonne cranes in a tandem lift with the cranes holding their lifts until a temporary connection had been made at the crown, packs placed under the base plates, and the nuts installed on the holding down bars at the two springings.

9. Arch half in Princess Road central reservation.

The cables were rigged and stressed in a further weekend possession of Princess Road. They were tensioned simultaneously in 11 asymmetric pairs to predetermined loads using hydraulic jacks connected to the adjustable anchorages at deck level. After all the cables were stressed, the tension in each was measured and compared with the expected value.

Lighting

Uplighters set into the side slopes on either side of the Princess Road cutting light the arch. The glow from red light-emitting diodes set into the bollards illuminates the footways and provides an effective counterpoint to the silver of the arch.

Conclusion

The bridge was completed in April 1997, 11 months after its commencement, and was formally opened on 10 May 1997 by Alex Ferguson (Manager of Manchester United Football Club). Also in attendance were Sir Bobby Charlton, the Lord and Lady Mayor and the Leader of Manchester City Council. The first vehicle to cross the bridge was the first Rolls Royce ever made, which had been manufactured near to the site. The opening of the bridge marked five years of the regeneration of the Hulme area of Manchester and in the evening was celebrated by a spectacular firework display at the bridge site.

Credits

Client:
Hulme Regeneration Ltd

Technical Approval Authority:
Manchester Engineering Design Consultancy (MEDC)

Engineers:
Ove Arup & Partners Andrew Archer, Simon Averill, Lesley Benton, Tony Bevan, Simon Cardwell, Bob Cather, Tim Chapman, Jane Collins, Colin Curtis, Peter Deane, Allan Delves, Ian Feltham, Joe Forster, Graham Gedge, Rob Gerrard, Ajoy Ghose, Fraser Gillespie, John Grainger, Andy Hawes, Chris Hawkes, Naeem Hussain, Gordon Jehu, Shirley Lavender, Ai Ling Lim, David Loosemore, Angus Low, Wendy MacLaughlin, Geoffrey Marchant, John McNeil, Roger Milburn, Avtar Muker, Chris Murgatroyd, Lars Nielsen, Duncan Nicholson, David Osborne, Craig Rew, Tony Sheehan, Roger Tomlinson, Ellis Walker, Stephen West, Mel Wheeler, Ian Wilson.

Architects:
Chris Wilkinson Architects

Quantity surveyors:
Bucknall Austin

Independent design check:
Mott MacDonald

Contractors:
Henry Boot Construction (UK) Ltd
Watson Steel Ltd (Structural Steel)
Bridon Structural Systems (Cables)

Illustrations:
1: Chris Wilkinson Architects
2, 9, 10: Peter Mackinven
3, 4: Peter Speleers
5, 6: Chris Hawkes
7, 8: Ian Wilson

6. Macalloy bars in 'rocket launcher' support framework.

7. Springing unit at fabrication shop.

8. Crown and quarter unit fitup, showing section at crown.

10. Arch erection.

Upgrading University Hospital of Wales, Cardiff

David Hay
Ray Lake
Graham Phillips

Introduction

The University Hospital of Wales (UHW) is the third largest healthcare provider in the UK. Covering a 24ha site in central Cardiff, it was designed during the 1960s as a multi-storey 850-bed general hospital, dental hospital, and medical college, with staff/student accommodation for some 500 people, and all linked by 4km of service tunnels. It is visited daily by up to 2500 people and in any typical day the population of the campus can exceed 5000.

Due to defects in the original construction, Arups' Cardiff Office had been commissioned to design and implement remedial works throughout the late 1970s and 1980s; then, in 1990, loss of Crown Immunity regarding Building Regulations identified the need for substantial improvements and upgrading, particularly in respect of fire precautions. It was then that the firm became involved in a long-term, £30M programme of diverse and demanding capital works projects.

Project scope

The initial appointment as project manager and lead consultant for the fire precautions upgrade came after a competitive bid: Arups offered the attraction of both being a 'one-stop shop' and having a co-ordinated strategy to deal with the complex problem of implementing the far-reaching measures required in a working hospital. Symonds were included as sub-consultant quantity surveyor.

Solving the fire precautions problem was necessarily complicated both technically and managerially, and needed Arups' full range of multi-disciplinary expertise. At the outset, a project management group and a design and fire group were set up to work in parallel on balanced solutions, taking account of the many constraints imposed by having to obtain the necessary fire certification with minimum disruption to all concerned. Careful co-ordination of all affected parties was essential.

Arups co-ordinated its in-house design and fire engineering skills with input from UHW itself, South Glamorgan Fire And Rescue Service, Cardiff City Council Building Control, and others, to produce a unified strategy. This also included project planning and financial projections, arrived at after testing various procurement methods and risk analyses relating to timing and ordering the works.

1. Aerial view of UHW, c1990.

The design team combined a 'fire engineering' approach with traditional methods, aiming to apply practical solutions including improvements to compartmentation and means of escape, formatting new lobbies, installing alarm and sprinkler systems, emergency lighting, and upgrading of lifts. Contracts were also needed to give new space for wards and operating theatres to move into temporarily during the works ('decant' space - in this instance on top of an existing four-storey block), plus general refurbishment and upgrading to all 21 wards on a rolling programme.

The team's initial thoughts were that a construction management method of procurement would be particularly suitable, given the number of distinct 'trade packages' and the need for close control of the workforce to minimise disruption both to and from the hospital users. The client, however, was not convinced, preferring to stay with tried-and-tested traditional procurement, so 40 separate JCT80 contracts were needed, ranging in value from £250 000 - £2.5M: all managed in accordance with standard NHS 'Capricode' (now *Capital Investment Manual*) procedures.

In parallel with these works, Arups also became involved in managing and/or designing other major elements of the capital programme, so that the firm's total site-wide works scope included:

- fire precautions upgrade to all buildings: wards, operating theatres, laboratories, office space, clinics, and accommodation, as well as the tunnels
- dental hospital refurbishment and extension
- upgrading 21 wards including bathrooms, bed space, and piped services
- re-modelling all ward-based kitchens for new 'cook freeze' catering
- refurbishing 45 lifts, including alarm-linked controls and new car interiors
- new extensions on second and third floor roofs for decant facilities, clinical space, and accommodation
- installing new security system
- PFI-procured multi-storey car park with 1400 spaces, plus new surface parking
- new highway interchange and bridge
- new pitched-portal roof enclosure to plant areas on top of main 10-storey ward block
- project managing a new £3M heart research facility
- design and management of new accommodation for the Trust for Sick Children.

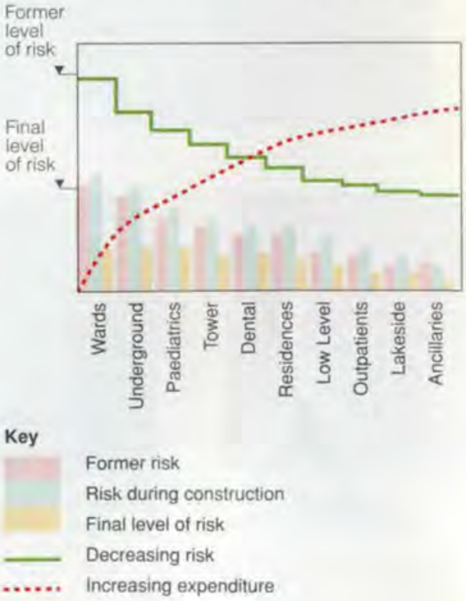
These further commissions extended Arups' range of services and consolidated the firm's experience and expertise in hospital work. It also acted as planning supervisor for several of the later schemes - a major challenge due to the multitude of operational procedures and legislation.

Programme and cost monitoring

In the main, the master programme was driven by the hospital's functions, taking account of the need to minimise disruption and to decant clinical space, and of out-of-hours working.

Acknowledging also the timing constraints imposed by Fire Notices, available space, and other building works on site, the order of works was prioritised and programmed over a notional five years. The 40 main contracts were each broken down into a separate sub-programme, identifying key dates for statutory approvals, compliance with the client's plan of work, certification procedures, and lead-in periods for pre-ordering. At any one time up to six contracts were on site, with similar numbers at both detailed design and planning stages.

The initial budget for each contract having been set, it was summarised on a master spreadsheet identifying all associated costs and the project total, and broken down into annual totals within which each year's works had to be contained. The costs for each phase were then monitored as the scheme progressed and fed back into the master summary to track the total budget. The most difficult costs to control related to changes in hospital operational policies and unforeseen elements in the existing building fabric.



2. Above: Organisation of project team principal members.

3. Right: Combined risk diagram showing, from left to right, the original prioritisation of the phases.

4. Refurbished operating theatre.

Operating theatres

As with all clinical spaces, the operating theatres needed decanting to allow building to take place. As well as new fire precautions, major refurbishment of the ventilation and air-conditioning was planned, together with re-modelled ancillary accommodation and a new recovery ward. However, income from operations is a major revenue source for any hospital and theatre 'down-time' is a significant cost. The political impact of longer waiting-lists was also a consideration. The suite contains 10 separate theatres and the compromise solution allowed closure of five during the traditionally less-busy time of year, for 10 weeks. Arups' strategy was to build first - in an additional back-to-back 16-week contract - a new temporary recovery ward and 'shell' accommodation: two pitched portal/clad structures on separate third floor roof areas.

Despite problems with the existing structure and re-commissioning existing theatre plant, both contracts finished on time and within budget. The refurbished theatres opened as planned and, with careful forward planning and additional operating 'shifts', theatre lists were largely unaffected. Arups has since converted the 'shell' space into a new 26-bed general ward.

Fire alarm and detection system

Arups' initial scheme showed the new fire-detection and alarm system to be fundamental to the fire strategy: the earlier a fire is detected, identified, and isolated, the sooner it can be dealt with and the adverse and disruptive effects mitigated. An analogue, addressable system serving the whole hospital complex was required, and initially the team looked at how various proprietary systems could provide the necessary features. The basic parameters were:

- cost
- quality and technical capabilities of the equipment
- proven reliability and simplicity of operation and maintenance.

After a two-stage tender process, Protec Fire Detection plc was chosen.

6. Main fire alarm control panels.

Within 12 months, following an intensive construction programme, a new, fully networked, multi-panel analogue addressable fire-detection system had been installed and commissioned throughout a large part of the site, providing widespread coverage of the complex. (At the same time, nine multi-storey accommodation blocks, five operating theatres, and other ancillary areas were also being installed and commissioned.)

The fire engineering techniques used in the subway system are outlined below.

A complex smoke-clearance system was introduced to avoid spread of smoke and remove cold smoke. For the system to work effectively, 21 clearance zones were formed, each including automatic sensor devices, manual call-points and alarms, automatic closing doors, electro-magnetically locked card access security doors, wall and door-fixed smoke dampers, smoke clearance fans and interfaces to passenger and service lift control systems. All the relevant parts were in some way directly connected or interfaced with the fire-detection system, using digital multiplexing techniques.

A special fireman's control and command centre was installed, allowing full status monitoring of each part of the smoke clearance zone. This gave automatic response communication to each component following a fire, and provided a dedicated fireman's remote override facility.

5. New temporary recovery ward, (built on top of fourth floor, see Fig 7 overleaf).

Designed to *BS5839*, incorporating the recommendations of *HTM82*, the system comprises stand-alone panels connected on a data highway network. The zoning of the building is not physically constrained by wiring loops as the system is software-driven and, therefore, site programmable.

When upgrading is complete there will be some 60 fully networked analogue addressable panels with 100 repeat indicator stations monitoring approximately 15 000 devices - one of the largest fully networked systems in Europe.

Lifts

Access to the hospital used to be via the lower ground and ground floor levels, confusing for visitors at the best of times, let alone during a fire alarm. The new arrangement was to terminate the lifts at ground floor, with in-car card access to the underground area for authorised persons. This provision supports the requirements of safety and security.

The existing lift installation is some 25 years old and in reasonable mechanical order, but the analogue control system, relying on mechanical linkages which mimic the operation of the lifts, was outdated and inadequate for fire precautions strategy needs. Also, these mechanical systems required much maintenance. The lifts were not linked to the fire alarm system, nor controlled in the event of a fire. Lift landing buttons were heat-sensitive, and thus tended to call lifts to the source of a fire. In the main hospital block they were powered by DC motors fed from an AC/DC generator - a relatively inefficient way of providing direct current, and needing a lot of maintenance.

The new requirements were to:

- replace the existing control system with microprocessors
- replace the AC/DC generators with static inverter/rectifiers
- replace the lift landing buttons and completely rewire in the shafts, using low smoke and fume trailing and control cables
- use *BS5588: Part 5* guidance for access and assistance to the Fire Brigade. (Some deviations were necessary and tolerated in bringing an existing hospital up to standard.)

Much care was needed to programme the works for minimal disruption; this involved lengthy consultations with hospital operational departments. Generally, only one lift per group was refurbished at any one time. In total, 45 lifts were refurbished throughout the hospital complex, making this the largest contract of its type in the UK.

7.
General view of ward block; on the left (built on top of fourth floor) is a new decant ward.

Wards

The hospital has 21 main wards, plus additional specialist wards for maternity, paediatric, and psychiatric patients. A programme for sequentially decanting each of these was formulated to dovetail with hospital requirements and work proceeded on up to three at any one time. Each ward phase had to be completed on time and budget to avoid unnecessary loss of revenue for the hospital.

Whilst the fire precautions work was relatively straightforward, the more complex betterment aspects - remodelling all the ward bathrooms/toilet areas, providing the individual 'cook freeze' facilities in an enlarged kitchen/store area, a new medical gas system, nurse call system, and controls for the heating system - were brought in to the typical 10-week contract period for a ward. All this needed detailed co-ordination to install the elements around the existing services.

The ward bathrooms were particularly difficult as the vertical mechanical services had to be diverted and repositioned, an exercise complicated by the fact that each ward could not be phased so that these works could proceed in a vertical plane. However, all completions, handover dates, and budget requirements were met for every ward.

Underground

UHW was designed to be serviced by a system of underground subways for supplies and staff, removing refuse, and site-wide distribution of piped services. All these happen round the clock, and the major constraint for this contract was to minimise disruption to traffic flow whilst the fire precaution work was under way. A traffic census assessed usage of the subways, and its results were used to plan and co-ordinate all the activities during the course of the works, but it became apparent very early on that it would be impossible to work in the major subways without some disruption to day-to-day running of the hospital.

Traffic flows were diverted in a co-ordinated way whilst essential fire precaution works like installing the sprinkler and hose-reel mains, ventilation ductwork, compartmentation, and cable-tray runs were carried out. Constant monitoring/liaison with the hospital staff ensured that most elements were carried out with minimum disruption.

Historically, most fire incidents had occurred in the subways, hence the installation of the card-access security system to restrict these areas and thus lessen chances of a major fire. A strategy was devised to limit underground access to essential users, involving extensive remodelling of all of the staircases, and introducing security doors at strategic locations through which traffic could be regulated and monitored. The lift car controls were altered to prevent access to the subways and both the security doors and lift cars were linked to the fire detection system to operate on a failsafe policy.

'Cause and effect' testing and commissioning of all alarm, security, and smoke clearance systems also required a major co-ordinated exercise with the hospital and Fire and Rescue Service; this was carried out in a series of night exercises which involved smoke-logging of strategic compartments.

Conclusion

Arups' input in the main hospital buildings ends early in 1998, with the last refurbishment contract for phased completion of the Outpatients Department (18 clinics with up to 1000 visitors per day).

The initial strategic approach, formed by Arup Fire in 1990, is still largely intact and it is interesting to note that recently published Hospital Technical Memoranda for fire precautions in existing hospitals sit comfortably with this original thinking. On balance, the strategy of combining the project management and design teams has worked well, and the client's 'project sponsors' formed an integral part of the team - a co-ordinating interface between the two seemingly incompatible professions of construction and health.

Credits

Client:
South Glamorgan Health Authority/
UHW Healthcare NHS Trust

Project manager, contract administrator, and engineer:
Ove Arup and Partners Ray Lake (project manager)
Peter Burns, Mike Cronly, David Hay, Nigel Lewis,
Mark McElligott, Rhodri Morgan, Pearse Murphy,
Glyn Parker, Graham Phillips, Nigel Richards,
Brian Whaley (contract administration and building fabric design)
Chris Jofeh (planning supervision)
Steve Bowen, Gerry Loader, Chris Lynn, Graham Philips,
Geraint Rowlands, Stuart Sargent (electrical)
Dylan Evans, Jonathan Griffiths, Peter Karabin, Phil Nedin,
Mike Rainbow, Brett Seeney (mechanical)
John Hopkinson, Martin Kealy (fire engineering)
Karen Andrews (project secretary)

Quantity surveyor:
Symonds Ltd

Main contractors:
Cowlin Construction, E Turner & Sons,
Trafalgar House, Costain Construction Ltd,
Balfour Beatty, Tilbury Douglas, Otis Lifts plc

Specialist alarm and detection system sub-contractor:
Protec Fire Detection plc.

Illustrations:
1: County Colour Ltd
2, 3: Jon Carver
4: Stephen Mitchell Photography
5- 9: Peter Mackinven

8.
Water tank and pump set for sprinkler system.

9.
Underground car park after fire precautions upgrade.

1.

The Cadbury confectionery facility, Chudovo, Russia

Mark Bartlett Robert Lindsay Fred Loterijman David Storer

Background

Cadbury Schweppes plc is one of the world's largest confectionery and beverage manufacturers, with operations in over 170 countries; its famous brands include *Picnic, Wispa, Cadbury's Dairy Milk* and *Roses*. Russia's 148M people consume over 500 000 tonnes of confectionery a year, making that country Europe's third largest market for the product. Cadbury Schweppes began exporting there in 1992 and in 1993-94 increased sales by some 300%, so with other Eastern European countries the whole region represents a significant part of the company's development strategy. In 1994 they completed a new facility in Poland and the success of this venture, together with clear market demand, led the Cadbury Schweppes board to give approval for a new confectionery facility in Russia.

Site selection

In late summer 1994 Arups was approached by Cadbury Schweppes' Technical Division to help them select a suitable site for the new facility. Arup staff in Moscow provided local knowledge to assist the Cadbury team assess about 20 sites between the major market centres of St Petersburg and Moscow; these were finally reduced to three for more detailed evaluation. In December 1994 Cadbury decided on Chudovo in the district of Novgorod, some 120km south-east of St Petersburg. The town has a population of around 30 000, its main source of employment being based on forestry and agriculture; industries include an ageing metalworks factory and two European/Russian joint ventures producing plywood and glassware. Chudovo is situated off the major M10 international highway linking St Petersburg and Moscow with Helsinki, and also has good rail links which will facilitate distribution of the product. When fully operational, the factory will employ over 350 people and so represents a significant boost to the local economy.

The chosen site was 10ha of previously undeveloped marshland, 2km west of Chudovo's town centre, and would have been classified 'greenfield' by British standards. However, due to confectionery's sensitivity to environmental conditions, considerable site testing - beyond normal ground investigations - was necessary. Because of the Chernobyl disaster, this included a radioactivity survey and a dust particle analysis of the atmosphere.

2. Location map

The project team

Following site selection, Arups was appointed as lead consultant and engineer, responsible for the full building and civil engineering design. An architect and a materials handling specialist nominated by Cadbury joined the Arup team as sub-consultants. The project was managed by Cadbury's in-house project manager supported by their technical staff. An important aspect of Arups' appointment was to provide technical support to Cadbury's engineers in developing the process design, so as to produce from the outset a fully co-ordinated building. In such projects the building design is commonly developed before completion of the process design, which often leads to unnecessarily prolonged development programmes and co-ordination difficulties when the manufacturing equipment is installed.

The final partner in the design team was a local design institute, Grazhdanproyekt, appointed directly by Cadbury Schweppes and based in Novgorod, the closest city to Chudovo. Their main role was to prepare design documentation for obtaining local approvals, and advise on acceptable design standards and typical methods of construction appropriate to the region. Experience had suggested that getting utilities to sites in Russia can often be problematic and Grazhdanproyekt's brief was extended to assist with this.

The brief

Cadbury's brief was straightforward. The new facility, totalling some 38 000m^2, was to produce 30 000 tonnes of chocolate per year initially and be capable of expansion by an additional 15 000 tonnes per year. The operating environment had to meet the high hygiene standards expected of food production premises and the recently-completed factory in Poland was established as the benchmark for this. Cadbury arranged for the design team to visit the Polish plant on a fact-gathering mission, an exercise which proved invaluable - particularly given the timescale set for the project. The target production date was set at June 1996: significant if the project had been in the UK - and extremely challenging for one in rural post-Soviet Russia!

For materials and workmanship the client desired UK-typical standards, but was keen to maximise on the use of local materials, construction techniques, and labour skills, since this was considered essential in achieving an economic building. Where possible the building design also had to be universal since, at the time of scheme development, details of the nationality of contractors and sub-contractors, and hence the sourcing of materials, were not known.

3. Front elevation.

Building layout and design

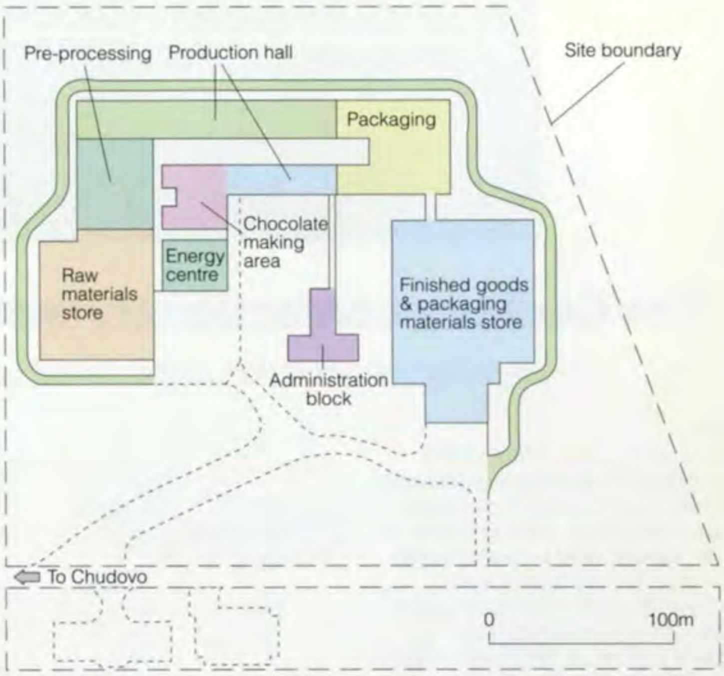
The process and building planning

The building layout is entirely dictated by the manufacturing process and the flow of materials through the facility. This is based on the principle, often used in food processing, of keeping raw materials away from finished goods or work-in-progress; materials flow logically from store to a pre-processing area, on to processing and production, then to a packaging hall, and finally to a store at the other end of the factory.

Following detailed studies, accommodation requirements evolved to achieve the 45 000 tonnes of chocolate production, (see Table 1).

Table 1

Function	*Approximate area (m²)*
• Raw materials storage	3000
• Pre-process area	2500
• Chocolate making building (all levels)	5900
• Chocolate production halls	6900
• Packaging hall	5200
• Central facilities	1300
• Plant areas	3800
• Finished goods storage and despatch	5800
• Offices and ancillary accommodation	1700



4. Site layout.

When raw materials arrive at the factory, they are palletised for storage, and then loaded into the racking system in the raw materials store. They usually arrive in forms that do not allow their direct use in the factory; this necessitates a pre-processing area to prepare them for ultimate use in production. Here nuts are roasted, and solidified confectionery fats melted and transferred into bulk containers.

The heart of the factory is the chocolate manufacturing area, where ingredients including cocoa mass, milk powder, sugar, butter, etc, are mixed and refined. The resulting liquid chocolate is held in surge tanks from where it is pumped to production halls for making the chocolate products.

The final product-making falls logically into two main activities, and so the production area is divided into a mould line (chocolate tablets) production hall, and a bar lines production hall (*Picnic*, *Wispa*, etc). These are supported by a central corridor - combined with a line of offices and ancillary facilities - which divides the total production area. The first floor above this support area forms a 'spine plant room', which enables utilities to be distributed throughout the production areas within a 'closed room', helping to maintain a hygienic environment.

All products finally arrive in the packaging hall where they are wrapped in their primary wrappers and then placed in cartons or display boxes. The completed pallets of product are then stretch-wrapped and taken to a marshalling area in the finished goods store. From here they are loaded into a VNA (very narrow aisle) racking system. When required, the pallets are extracted from the racking, taken to the dispatch marshalling area, and loaded into despatch vehicles.

The amenity building, incorporating offices and staff facilities, is located away from the factory, enabling future expansion of the production areas.

5. Front of administration block.

6. Energy centre (foreground), with the chocolate manufacturing building behind.

Architecture

The building design had to be functional yet retain the aesthetic characteristics of a modern Cadbury Schweppes facility. This was achieved through a very simple building form wrapping around the manufacturing process: each functional area treated individually with regard to its particular spacial requirements, but the total manufacturing space covered by a common roof that varies in height and form.

The building is clad in conventional sandwich panels detailed to provide the clean environment necessary for the facility, with particular attention paid to the joints to provide adequate seals against dust and insect infiltration. Due to the wide temperature variation in the region (+30°C in summer to -27°C in winter), considerable effort in the design, detailing, and specification was necessary to maintain acceptable operating temperatures within the plant.

Points of entry to the building have to be effectively sealed against external contaminants and this is achieved through double lobbies and careful detailing. Other design principles to create hygienic conditions included minimising ledges and surfaces that could gather dirt or dust and eliminating non-cleanable surfaces. Production areas do not contain any glazing because incident sunlight can damage products. Windows are generally prohibited in food manufacturing areas since insect ingress is a perpetual problem where they exist.

Structural engineering

A steel-framed solution was adopted early in the scheme's development, since this was considered the most appropriate material in view of programme constraints and the likelihood that the superstructure would be constructed by a non-Russian organisation.

The structure generally comprises a number of portal frames of varying span and height supported on simple pad foundations, the exception being the building containing chocolate manufacturing, which created the greatest structural challenge.

Experience from another recently completed Cadbury factory suggested that the chocolate manufacturing machinery would impose significant dynamic forces. Loading characteristics of the various items of equipment were therefore obtained from the vendors to assist in the design, but these were found to be unreliable as a basis for designing the support structure. This was further complicated by the inability to determine coincident loads, in particular those occurring at 'start up'. Arups had to carry out a quasi-dynamic structural analysis based on the likely operating environment suggested by Cadbury's process engineers. Machine-weights were modelled as nodal masses and analysed to find the dynamic response of the structure. The frequencies of the natural modes of vibration were then compared with the operational frequencies of the machinery to establish a sufficient margin of safety against resonance occurring. Following this analysis, a conservative design approach was adopted for the structure and its foundations.

The chocolate manufacturing building is founded on a 600mm thick, 42m x 30m, reinforced concrete raft, locally thickened beneath points of high loading intensity. This assists in spreading dynamic loads to the relatively poor ground as well as providing a convenient structure to support high point loads imposed at ground floor.

7. Energy centre, showing chiller in the foreground.

Central utilities

The design philosophy for the production and distribution of power, heating, and cooling utilities was to locate the major plant in an energy centre as close as practical to the load centres, and to route these and other utilities outside the production spaces. The energy centre, placed close to the chocolate manufacturing area (the single largest consumer of power from process, heating and cooling systems), comprises four distinct spaces: the air compressor water treatment and pump room, the chiller plantroom, the steam boiler plantroom and the transformer and switchgear room.

Incoming mains water is filtered outside the plant before distribution to the factory and to the water treatment plant in the energy centre. The water is treated to achieve two different qualities, one for process, the other for steam generation. Three steam boilers, each nominally capable of generating 5000kg/h of steam at 11 bar, were installed. Two boilers can meet the current demand with the third on standby. Space has been allowed for a future fourth boiler.

The cooling plant comprises three skid-mounted screw compressor units using ammonia as the refrigerant and to cool a propylene glycol brine to -2°C as the distributed cooling medium. Each refrigeration unit is rated at a nominal 2.5MW of cooling. Two units satisfy the factory cooling load, the third being on standby. Ammonia was selected as the primary refrigerant partly to accord with Cadbury's green policy to adopt environmentally friendly design solutions, and partly in response to local familiarity with this technology.

Steam and -2°C glycol are piped directly to the adjacent chocolate manufacturing area. This reduced the length of piping runs to the major process loads and also results in smaller diameter main piping to the other production areas.

Most of the air-conditioning plant, the process heat exchangers, and the power distribution boards are located in the spine plantroom, which is also the route for distribution of piped services, for pumped chocolate, and for pneumatically conveyed powder ingredients.

Electrical services

The production facility has an electrical capacity of 16.8MW, derived from a Cadbury refurbished 110kV-10kV dual substation about 500m from the new plant. The site is serviced by two independent 10kV feeders, each capable of supporting the production demand.

The two supplies terminate into a primary switchboard in the energy centre, where three 2.8MVA cast resin package substations supply the main chiller plant and ancillary buildings. Three additional 2.8MVA cast resin package substations are distributed within the spine plant room adjacent to the centre of production load, ie the chocolate manufacturing area and production halls. The distributed transformers are supplied using an open 10kV ring network fed from the primary substation in the energy centre.

The use of remote package substations avoided a lot of low voltage cabling and provides the power where it is needed practically and economically. Radial cable feeds from each substation emanate to sub-distribution boards, process control panels, mechanical HVAC control panels, and building services distribution boards.

Due to the absence of any natural daylight in the facility, energy-saving lighting is installed throughout - mainly highbay metal halide luminaires and sealed fluorescent fittings for easy maintenance, rated to *IP54* (the BSI-approved ingress protection level that is effective against insect infiltration). All electrical distribution equipment and lighting have to be sealed to *IP54* to satisfy the required hygiene standards. Communication and security systems, as well as emergency back-up systems, are also provided to a level of specification typical for the UK.

Environmental services

The +30°C to -27°C design ambient temperature range challenged the design team to engineer air-conditioning systems giving reasonable space temperature control at either extreme of external temperature, with or without large heat gains from process plant. The internal design temperatures were generally to suit comfort conditions for the staff, except in the chocolate manufacturing area where the design intent was to limit temperature excursions above reasonable maximum, and in the warehouses where lower design temperatures were required to provide suitable storage conditions for the raw materials and finished goods.

Humidity control was only required for the packaging hall where the design criterion is to maintain the space dewpoint below the temperature of the product emerging from the cooling tunnels.

Except for the packaging hall, the population densities in the production areas are relatively low, which meant that fresh air could be reduced to the minimum permitted by design codes, thereby improving energy efficiency when the external ambient temperatures approach the summer and winter extremes. The systems are designed to achieve further energy savings by using outside air for free cooling at suitable outside temperatures.

Process engineering

Process services

The factory is designed to produce a variety of Cadbury's products, including moulded chocolate bars and bar lines like *Picnic*. The processes are the manufacture of chocolate for moulding and for inclusion in and coating of bar lines, the baking of wafers, and the preparation of fondants, creams, caramels, and other constituents of bar and confectionery lines.

The design principles and detail of the process flows, as well as the process equipment selection and procurement, were undertaken by Cadbury's project team. They also co-ordinated the flow of information from the process equipment manufacturers to Arups' design team. Arups worked closely with Cadbury's process engineers to produce the schematic process layout diagrams and detail plant and piping drawings. In order to receive the latest details and information on process equipment, modem links were established with Cadbury's vendors in Austria, Canada, Germany, Italy, Spain, and the UK.

This information, which generally comprised manufacturer's equipment general arrangement drawings, was then incorporated into the factory layout drawings and enabled accurate development and co-ordination of the process and the process utility piping drawings.

Process utilities

The chocolate and chocolate bar product-making process is energy-intensive and requires a variety of heating and cooling media for the various processes. Heat exchangers and buffer tanks for process heating and cooling were sized by Arups to suit the required process temperature profiles defined by Cadbury's process engineers. The cooling systems in particular were designed to reduce peak cooling loads on the main refrigeration plant to reduce the plant frame size and reduce the consequent electrical demands.

The distributed process heat source is 8-bar steam, which is used directly in the process and to produce hot water at 90°C and 45°C for ingredient making, for tempering and for jacketing of chocolate pipelines. Propylene glycol brine at -2°C is the primary medium used in cooling tunnels to cool the product before packaging, and to provide cooling water at various temperatures for heat rejection in vessel jackets. Other process utilities include compressed air and nitrogen.

Water for use in chocolate or ingredient making is filtered and softened to meet Cadbury's product specification. Water for heating and cooling in jackets with no product contact is only filtered.

Construction in Russia

Since the formation of the Commonwealth of Independent States (CIS) in 1992, access and assistance for foreign investors wishing to develop in the country have clearly improved. However, the logistics of developing a manufacturing facility in Russia are still nonetheless formidable. Apart from the many extra technical and administrative tasks necessary, there are inevitably difficulties regarding the acceptance and availability of 'Western' methods, materials and products. In some instances these may be specific to the region where the project is located, in others they may be a result of national requirements. The difficulty is establishing all requirements for a particular project, and this alone can take considerable effort.

8. Caramel making plant.

TEO approval

The first requirement for any proposed construction project is to obtain TEO *(Tekhniko-ekonomicheskoye obosnovaniye)* approval, which involves submitting to the appropriate authorities a detailed document that provides a technical and economic justification for the project. The TEO is a remnant from the time when all projects were effectively state-financed and therefore required justification by the State. TEO approval, however, remains a prerequisite for any new project since this triggers the building permit that must be obtained before any works can start on site. The TEO requires consideration of all aspects of the building design, from the nature of the construction materials used, to the emissions and discharges generated by the manufacturing process.

Due to the demanding schedule, preparing the TEO document became a critical activity and therefore had to be produced in advance of the detail design. In consequence, much of the detailed information necessary to compile the document was not available, nor were the specific requirements for the TEO fully understood. To overcome these difficulties Arups put a Russian-speaking engineer from the Moscow office into Grazhdanproyekt to liaise between the UK design team and the local consultants, to ensure the necessary exchange of information took place.

Programming

Effective programming is influenced as much by the many necessary pre-contract activities, as it is by actual construction work.

These include formalities like land acquisition, local company registration, TEO approval, and securing services to the site. In addition, numerous sanctions, licences, permits, and approvals are necessary to progress the project.

The period required to obtain all of these is impossible to predict since it is dependent on many factors like project complexity, the familiarity of the authorities with the manufacturing process and, most importantly, the co-operation of the regional administration and local authorities.

The availability of local staff to clarify matters and resolve queries is therefore a pre-requisite for effective programme control.

The availability of materials within Russia also has a significant effect on project procurement. Whilst most materials commonly used for an industrial project of this nature are available - albeit to a standard of specification at variance from what is typical for Western Europe - delivery times are unreliable. Receipt of imported materials and goods is often delayed due to bottlenecks at Customs, a factor that often results in considerable overruns in the completion of projects.

9. Wafer oven and sheet cooler.

Construction

Programme

The original development programme was set by Cadbury's desire to commence chocolate production in June 1996. For this to be possible, large areas of the building had to be watertight before the onset of winter. This would then permit the floor slabs to be built under a controlled environment during the winter months, enabling fit-out of the manufacturing equipment and services to commence.

The design and procurement of the structural frame and foundations, together with the cladding, were obvious early critical path activities.

The primary areas from a process and servicing requirement were the chocolate manufacturing area and energy centre and these therefore formed the key early activities. Once the building was watertight it was considered that all follow-on activities could progress conventionally, unaffected by 'external' influences.

Procurement

The original intention was to use a construction management route, and early design activity progressed on a construction package format with eight main packages initially being identified. However, in attempting to let the first advanced works package it soon became apparent that conventional construction management procurement was not going to be appropriate for this project. Apart from the normal issues of managing the interfaces between packages, it was evident that, due to the difficulties in sourcing materials and the need to obtain numerous approvals, this could best be achieved by a large contractor familiar with the area and licensed to operate in the region. As a consequence the procurement strategy was adjusted to reduce the number of construction packages to just three:

- steelwork frame including cladding
- civils and building works
- electrical and mechanical services including process services.

These packages were then managed by a site team established by Cadbury comprising all the necessary skills and disciplines. Arup staff assisted this team on an ad hoc basis during construction.

Site activities

Due to complications in letting and setting up the main building works package, major work could not commence on site until October 1995, some five months behind the original programme. The challenge was then set to commence building the factory through a Russian winter.

All concrete for the works had to be manufactured on site and due to the cold this was produced using steam-heated aggregates and hot water. During the early months of the project the batching plant towered over the site, steaming day and night. Only sand was locally available, with the granite aggregate and cement arriving daily in trucks from north of St Petersburg. Mass concrete bases were rapidly placed between October and December, by which time all foundations to the 210m long production and packaging hall had been poured. November had brought the first snow and below freezing temperatures and during December the lowest daytime working temperature was recorded at -23°C.

The critical base to the chocolate manufacturing area was imaginatively constructed by the Finnish contractor. After removing areas of soft material, a 300mm thick granite capping layer was placed. A sandwich blinding was then formed comprising a lower concrete layer with heating cables cast in, a 50mm layer of low compressibility insulation, and a top layer of concrete blinding. The heating cables were then used to ensure the formation was kept above freezing throughout concreting. The raft was completed by Christmas 1995.To maintain progress, steel erection to the production and packaging hall started in November on a freezing, snow-covered site with diminishing daylight hours. It was a daunting task. Nonetheless the British steelwork erectors managed to complete the frames to the major store buildings between January and March in parallel with the chocolate manufacturing building.

The pace of work and highly frost-susceptible clay caused serious problems for the ground slab construction. At worst, under normal exposed areas the frost penetration was 800mm, but under trafficked areas the frost penetrated 1.4m. The target completion date meant that slab construction could not be delayed, so the frozen clay was dug out and replaced with sand fill. Steam heating blankets were often required to thaw the sand, with excess water being pumped out and the sand re-compacted. Having completed the extensive formation preparation area by area, the slabs were cast using the long strip method. This was new to the Finnish contractor, but proved successful with all slabs well within the specified tolerance.

Installing foul and storm drainage began in January 1996. The frozen ground resulted in all trenches having to be 'pecked' by a rock breaker before excavation could commence. The exposed clay soon froze and no temporary support was necessary - an unexpected bonus of winter working. Civil works began in earnest after the worst of the winter. The extensive drainage installation was connected to foul and storm pumping stations and the site then remained dry for the completion of the contract - a significant contrast to the boggy, mosquito-infested area of the previous summer.

Conclusion

Cadbury's new factory at Chudovo was not the first 'Western' factory to be built in Russia and will certainly not be the last. It was, however, completed in an astonishingly short time, even by Western standards, and is therefore a testament to what can be achieved with the right will and determination in an environment not accustomed to 'fast track' construction.

Despite a delayed start on site, Cadbury produced its first chocolate in September 1996, just three months later than the original production target. The factory was finally completed in December 1996: a remarkable achievement for all involved. Particular praise must go to the contractors and site staff who were resolute in their determination to complete the job, often under difficult circumstances in the, at times, challenging climate.

The project represents the largest single investment in a greenfield site Cadbury Schweppes has made, its total cost being some US$120M. In order to complete the project:

- Over 10 000 tonnes of goods were imported from more than 20 countries.
- More than 800 customs declarations were prepared and processed.
- Some 250 certificates, licences, permits, accreditations, etc, were acquired.

Credits

Client:
Cadbury Schweppes plc - Group Technical

Civil and building works contractor:
YIT Corporation (Finland)

Structural steelwork and cladding contractor:
Romein Staalbouw (Netherlands)

Lead consultants and engineers:

Ove Arup & Partners
UK Core Team: Davar Abi-Zadeh, Mark Bartlett, Keith Beckett, Ian Burwood, Andy Davies, Damian Friel, Diane Gilchrist, John Harvey, Stuart Jarvis, Rob Lindsay, Nigel Livingstone, Fred Loterijman, Keith Rudd, Ken Sharp, David Storer, Ken Whale, Peter Wright, Gareth Young, Robert van Zyl (Engineering)
Ray Bennett, Wayne Charles, John Corbett, Gill Gardiner, Lee Gill, James Kirby, Brian Rogers, Diane Sadleir, Wal Scarr, David Stanley, Jared Waugh (Drafting)
Moscow Core Team: Frank Ryle, Moyi Dahiru

Arup sub-consultants:

Architect:
Mason Richards Partnership

Materials handling specialist:
MMM Consultancy Group

Local design institute:
Grazhdanproyekt

Illustrations:
1, 3, 5-10: Peter Mackinven
2: Denis Kirtley
4: Jon Carver/Emine Tolga

10. Administration block.

Printed in England by Reedprint Limited, Windsor, Berkshire