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Billingsgate Fish Market refurbishment

Architect:
Richard Rogers Partnership Ltd.

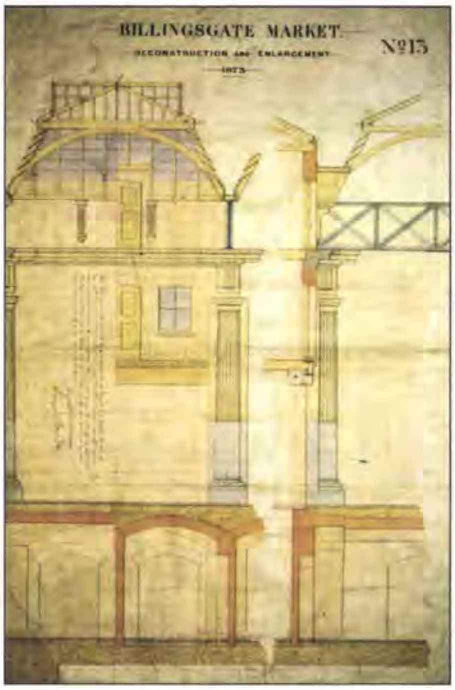
Roy Smith
Ian Wattridge

Introduction

The old Billingsgate Fish Market, situated on the north bank of the Thames by London Bridge, was built under the direction of the Corporation of London City Architect, Sir Horace Jones, in 1874-77. Substantial structural modifications followed in 1909, and ultimately the building was used for just over 100 years for fresh fish sale and storage. In 1982 the Market moved to new premises, leaving a building with no heating system and frozen basement cellars. Three years later, Citicorp Investment Bank, one of the world's largest, purchased it for conversion to a modern financial trading house.

The original building

The large ground floor, open to the timber roof and glazing above, and known as the Market Hall, was and still is surrounded by two and three levels of offices on its north, east and south sides, the Hall itself being divided in the north/south direction by a structure at second floor level known as the Haddock Gallery. The overall dimensions of the building are about 64m east/west and 59m north/south. Ground floor level is at about 5.65m OD, the second floor at 13.95m OD, and the third level, which exists only in the south wing, about 3.7m above this. Fourth floor levels are present only in the towers at the south-east and south-west corners. The basement areas went down to 7m below the high tide level of the Thames, with the top of the existing raft at approximately −2m OD. The building is Grade 2 listed; thus any conversion scheme had to retain the basement vaulting, the external walls, the roof, and its supporting structure.



1. Billingsgate Market reconstruction: a drawing prepared in 1873 (Reproduced by courtesy of The Corporation of London Records Office).

Existing superstructure

Over the Market Hall the roof is supported on timber arches spanning north/south at 550mm centres, carried by wrought iron lattice trusses spanning east/west at 6.9m centres. The lattice trusses at second floor level span about 18.6m onto cast iron columns, each of them about 0.8m in diameter and located at the east and west walls of the Market Hall, and on the east and west faces of the Haddock Gallery.

The vaulted roof over the length of the Haddock Gallery is also supported on timber arches at 600mm centres, which are carried on load-bearing brick walls, running north/south. The walls are in turn supported by wrought iron girders spanning between the cast iron columns. The floor in the Haddock Gallery is of concrete construction, carried on curved iron plates arching between transverse wrought iron beams at 2.3m centres.

Existing substructure

Under the Market Hall, a system of brick masonry vaults and piers supports the ground floor and cast iron columns above.

These piers are at 6.92m centres, running north/south. In the east/west direction the span of the vaults directly beneath the Haddock Gallery is about 9.3m. On either side the three spans of the vaults measure 6.3m, 5.8m and 6.3m respectively.

The loads from the north, east, south and west facades of the Market Hall are carried immediately below ground level to brick walls, piers and arches, through to foundations, at basement level.

The outer facades of the building are supported by the river wall and the retaining walls underneath. The former, and probably the north retaining wall as well, is of double skin masonry construction, infilled with weakly cemented masonry gravel.

The river wall is faced with granite about 3.5m thick overall, and supplemented by infilled buttresses below. The east retaining wall, also masonry, is buttressed by cross-

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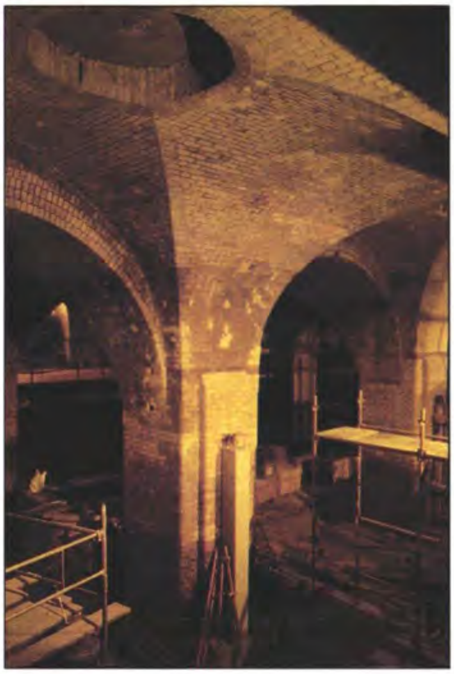


6▷

7▽

2. & 3. Original roof timbers

4. Roof under construction showing temporary works

5. & 6. Vaults during conversion

7. First level basement after conversion

walls at 6.92m centres, under the cross-walls that existed above; the buttresses in the east and south walls form chambers, which are also to be found in the north wall and under the four corner 'towers' of the Market.

Finally, the brick masonry of the substructure, vaults, piers and retaining walls is supported on a concrete foundation slab, taken down to the London Clay and on the original drawings shown as about 3m thick.

The client's requirements

The scheme prepared by Richard Rogers Partnership aimed to relate sympathetically modern stylistic details and services to the traditional structure of the original building. During the period following their purchase of Billingsgate in 1985, Citicorp were obliged to upgrade their specification a number of times due to the rapid rate of change in the financial services sector. However, a basic requirement remained the creation of a large dealing area on the ground floor suitable for 475 trading desks.

A new, lightweight steel demountable mezzanine floor has been inserted between the Market Hall ground floor and the Haddock Gallery, following the line of the latter and extending at each end of it along the east and west edges of the building to form an I shape on plan. It is unenclosed and overlooks the trading floor below. The galleries on the perimeters of levels one to three will be used for meeting rooms and offices, those on the south side for senior management having views of the Thames.

The basement has been divided into two levels, with a central double-height area. The newly-constructed floors in this first basement area, under the refurbished brick barrel vaults, will be used for back-up financial services. This part has a glazed wall overlooking the lower basement salad bar which occupies the double-height section, utilizing the full 7m depth of the original cellars. The remainder of this second (and lowest) basement level incorporates a computer area, in addition to the salad bar's kitchen. This level also contains plant including large separated areas for the chillers, boilers and diesel generators.

Early in the design process it was discovered that there was insufficient space within the basement and the roof to accommodate all the water and services storage tanks that were going to be needed. A tank room was therefore built 7m into the Thames and underneath the existing jetty, accessible from the lower basement level.

Refurbishment works

Most of the original structure is listed Grade 2 and has been retained in the scheme, including the timber roof arches, wrought iron lattice trusses, cast iron columns and wrought iron beams and plates forming the Haddock Gallery. The main structural works in the refurbishment included the following:

Superstructure

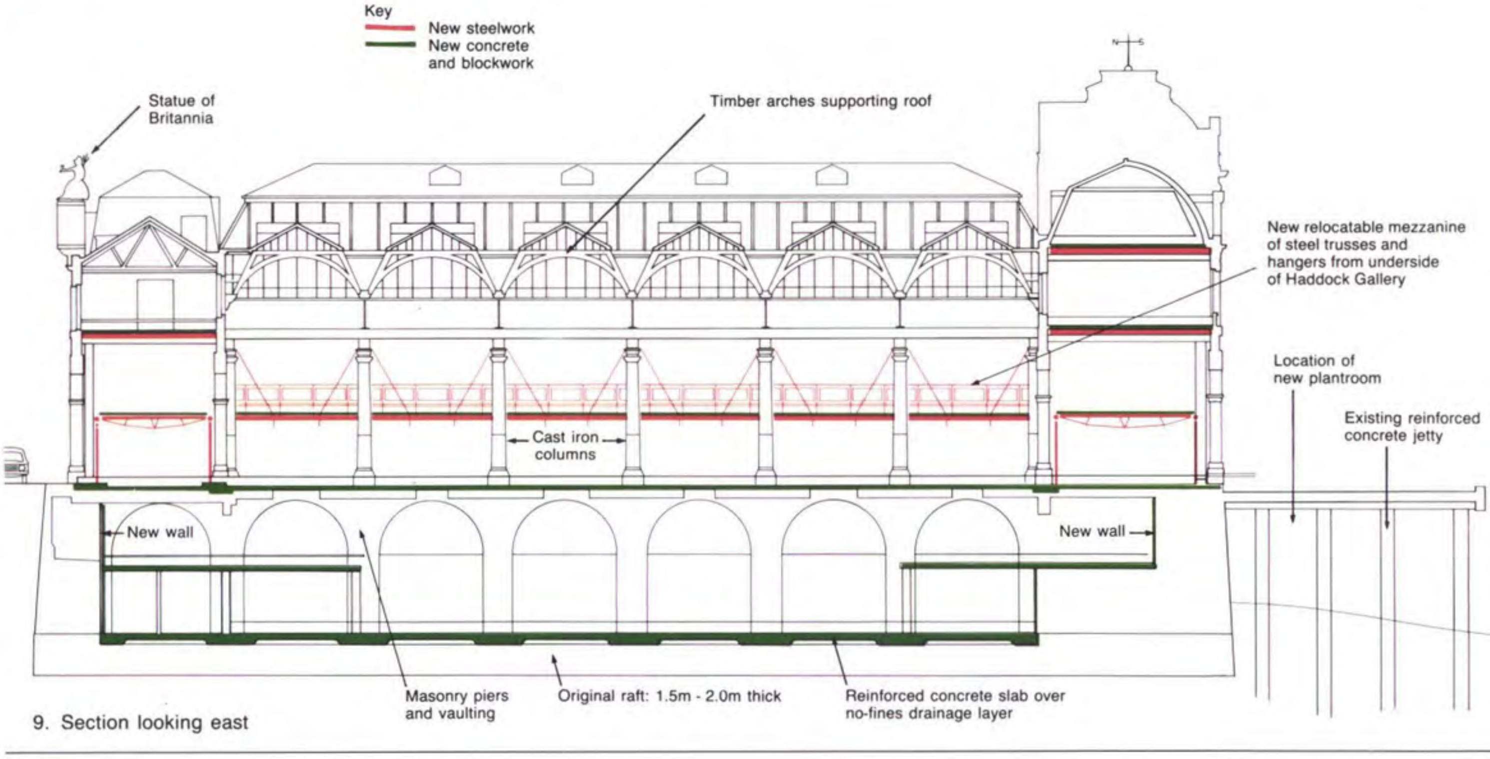
Significant remedial works to the timber roof arches were found to be necessary, with many members having to be replaced because they had rotted. In the Haddock Gallery new steel ties were installed to restrain the lateral spread of the feet of the trusses, and the Gallery floor was also strengthened (for the new suspended first floor beneath) by casting reinforced concrete beams alongside the existing wrought iron ones.

The south wing barrel roof, above the third floor level, was strengthened and stiffened with steel portals and the whole roof recovered in new lead, laid in the traditional way with rolls and drips.

Few repairs were needed to the wrought iron elements, which only needed cleaning, painting, and fire-protecting with smooth 'thin film' intumescent paint to give the one-hour fire resistance required by the Building Regulations. Fire protection to beams in the steel frameworks of the north, south and east wings was by dry-lining with fire-resistant boards. The cast and wrought iron metalwork of the Market Hall was also treated with intumescent paint, but the cast iron columns needed no fire protection to achieve the one-hour duration.

New superstructure slabs at first, second and third levels, necessitated by the architect's requirements, were cast in lightweight, 125mm thick reinforced concrete on metal

8. Interior showing new demountable mezzanine floor



9. Section looking east


10. First floor, south side


11. Third floor, south side


12. Ground floor, south side

decking, and were supported on new structural steel framework which was also used to restrain laterally the perimeter walls of the Market Hall.

Temporary works

Extensive systems of temporary works were designed in structural steelwork. These underpinned the high level brickwork (above second floor level) along the north and south internal elevations of the Market Hall whilst new colonnade structures were installed, thus reverting the Market Hall elevations to the original Jones design, removed probably in the 1909 modifications. Vertical jacking was used to control deflections during the underpinning and load transfers.

Temporary works also laterally braced the roof and restrained the north, south and east wings, whilst the original timber floors were removed, and remained in place during installation of the new slabs at second and third levels. In all, the temporary works were in place for about six months and the cost was over £0.5M.

Stability

The gutting of most of the original floors and internal walls rendered the installation of new stability systems necessary. The slabs at third, second and ground floor levels linked new reinforced concrete cores and shear walls (at the north and south ends of the Haddock Gallery) with steel vierendeel frames at the east and west ends of the north and south wings, and with the slabs and external wall in the east wing.

A new reinforced concrete ground floor slab 250mm thick was cast over the top of the brick vaults, with integral reinforced concrete beams to transfer loads from new steel stanchions in the superstructure into the main brick piers in the basement, and positively connect the superstructure to the substructure.

Substructure

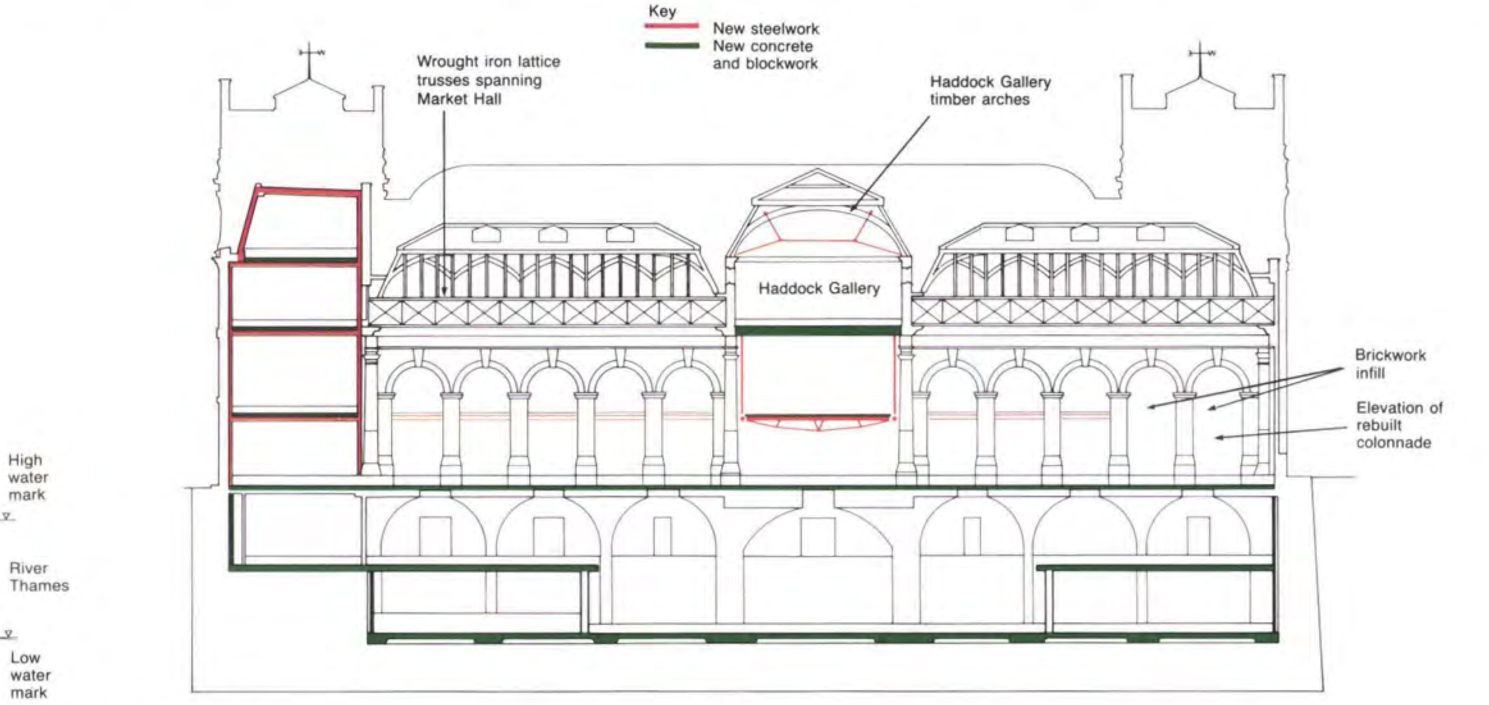
A new reinforced concrete basement mezzanine slab was supported on new reinforced concrete columns built off the lowest slab and foundations. A programme of remedial works to the vaulted substructure included grouting to cracks in the vaults, as well as replacing and making good defective and missing bricks. Vaults that were badly spalled have been relined with 50mm thick render (carried out in two halves with stainless steel mesh anchored to original brickwork) and now almost look more like bricks than the real thing!

A drained cavity was formed behind a skin of concrete blockwork against the retaining walls between basement level and the underside of the ground floor level, and linked to the groundwater drainage layer under the basement slab.

Remedial works to the existing retaining walls consisted of a programme of stopping leaks using both cement/bentonite and chemical grouting, carried out by specialists.

A new reinforced concrete basement slab was cast over a new damp-proof membrane and a no-fines drainage layer with perforated drains linked to sumps.

The original 'concrete' raft varied from 0.5m to 1.8m thick, leaked, and was generally in a poor state over the top 300mm or so. In order to restrict the flow of water from outside the building, which found its way under the retaining walls and up through the old raft, a grout curtain was injected into the underlying layer of ballast and clay, and into the existing 'porous' raft around the perimeter of the building.



13. Section looking south

14. Location of River Thames plantroom

Relocatable floor

New technology amongst the original listed structure is represented by the new mezzanine, a lightweight reinforced concrete deck supported at 3-4m centres by tubular steel trusses. In the central area it is suspended from tubular steel 'diagonal' hangers attached to the underside of the strengthened Haddock Gallery, within the north and south colonnades tubular steel posts standing on ground floor plinths support the new deck.

This exposed steelwork, like the wrought iron elements, is fire-protected one hour by smooth intumescent paint about 1.7mm thick — especially developed for this job in order to show the 'fine' details of the castings at the node points of the steel trusses.

River Thames plantroom

Structural works necessary to construct this new storage area included breaking out the existing reinforced jetty structure to create space for a sheet-piled coffer dam, and the installation of steel H-piles to resist flotation of the plantroom. The reinforced concrete base slab and walls were cast in watertight construction and secured and sealed to the existing river wall (the slab level matching the existing basement level) to form the 19.5m × 7m × 7m plantroom. As a second line of defence, a no-fines drainage layer and cavity was constructed to collect any water that might leak through, and linked with the drainage systems in the basement area.

The flood defence level had to be maintained whilst construction works were completed and before eventually breaking through the existing river wall (approximately 3.5m thick) to create a 'tunnel' link between the new plantroom and the existing basement.

Air-conditioning, ventilation and mechanical systems

The refurbished Billingsgate Market is fully air-conditioned. 15 separate air-handling areas had to be installed, this unusually high number being necessitated by the fact that the existing structure did not allow for larger and fewer areas.

The dealers' area, ground floor

Conditioned recycled air is introduced through a raised metal floor and into the room by air swirl diffusers. 12 air-handling units, custom-built to the architect's design, are located around the perimeter of the room, accepting recirculated air at the top and discharging conditioned air into the underfloor plenum void. Along the north and south glazed perimeter walls, fan coil units are located under the floor to offset fabric gains and losses.

Three air-handling plants serving the dealers' floor are located in separate plantrooms on the first and third floors. They supply conditioned fresh air through ductwork to mix with recirculated air in the underfloor void. Extract air passes to high level within the Market Hall and discharges through fans mounted in the glazed roof.

Both the fresh air and the recirculating units supply air at 17°C to the underfloor plenum, humidity control being provided by the former.

Office floors

The three office levels above the ground floor are air-conditioned by variable air volume systems. These utilise recirculated and fresh air which is mixed, conditioned and supplied through medium velocity ductwork routed within the raised metal floor voids. Eight systems, located in seven separate plantrooms, supply air to terminal units located within the office underfloor, and ducted into the office areas through floor-mounted swirl diffusers. The air quantity is controlled by thermostats at the terminal units, and a reheater battery is provided within each unit should office heating be required.

The room air is returned to the plantrooms through high level grilles for the upper levels and through linear perimeter floor grilles for the basement office area. The plant incorporates motorized dampers which control the proportions of fresh and recirculated air. This arrangement allows the dampers to provide fresh air 'free cooling' when air conditions permit.

Constant volume terminal units on the first and second floors supply air through 'punkah' louvre outlets directly onto the large glazing areas to offset extreme ambient conditions and prevent condensation.

Basement offices

The last three of Billingsgate's 15 air-handling systems serve the basement offices; these VAV installations are located in three separate basement plantrooms. The lowest basement computer and ancillary areas are served by free-standing units with standby. Also the salad bar, kitchen, UPS (uninterrupted power supply) room and workshop are air-conditioned from separate plants.

Satellite computer cabinet rooms located within the first basement and second floor each have duplicated air-handling units; plantrooms and toilet areas are dealt with by separate plants.

Cooling and heating sources

Five water chillers are located in a basement room. Three centrifugal units (two duty, one standby), each with a cooling capacity of 800kW, serve the main part of the building, whilst two 300kW reciprocating units (one duty, one standby) supply the computer suite, UPS area and satellite rooms on 24-hour operation.

From the units, chilled water is supplied at 8°C on a primary circuit to serve air-handling units and returns to mix, and provide a 13°C secondary unit for dealers' air-handling units and fan coil units. All pump circuits operate on run and standby and incorporate pressurization and water treatment units.

Three forced draught cooling towers (two duty, one standby), located within an acoustically louvred roof plantroom, cater for the heat rejection from the building and computer suite systems and provide cooling water at 29°C. However, when the ambient wet bulb temperature falls below 8°C, the towers will generate cooling water at 11°C which, through plate heat exchangers, provides secondary circuit chilled water with the chillers shut down.

15. Free-standing AHU on ground floor

Two other cooling towers (one duty, one standby), serve only the emergency generators.

Two natural gas-fired boilers, located in the basement, provide hot water at 82°C flow, 72°C return, to air-conditioning units, general heating area and ventilating systems. The heating capacity of each is 600kW.

The Thames plantroom houses storage tanks for cold and treated water, hose reel, and oil for the emergency generators. Within the building, the majority of the plantrooms have raised floors allowing the pipework and most ductwork to be routed beneath the plant level. The building is provided with a sprinkler system at Citicorp's request, the supply being taken from the Thames Water Authority main.

Electrical engineering

The electrical supply is provided by the LEB with an 11kv, three-phase radial supply rated at 200A/phase (3.8MVA). The substation with its high-voltage switchgear, metered on a maximum demand tariff, is located within the first basement. The switchgear consists of vacuum-type circuit breakers with two 200A-rated outgoing sections leading to two 2.2MVA 11kV/415V dry-type air-cooled transformers located in the lower basement. 4000A busbars supply the main switchboard in two sections, which under maintenance load conditions can be fed from a single transformer without shedding.

Two 1.25MVA, 1500rpm, water-cooled diesel generators are provided in the lower basement. In the event of mains failure the generators will start automatically and re-energize the main switchboard within 30 seconds. The generators will supply the full building load; no shedding is required and full trading business can be maintained.

Two uninterruptible power supply systems give continuous, no-break feeds to essential computer and dealer communications systems. One is rated at 300kVA for the computer suite and communications centre, and the other at 500kVA for the dealers' and office areas.

Natural lighting to the dealers' floor is controlled using a system of prismatic glazing units in the old Market Hall roofs. These units are designed to exclude direct sunlight with its associated glare problems by a process of total internal reflection and refraction, and to accept light from the more favourable northern sector of the sky. A similar prismatic system is used over the Haddock Gallery.


16. Diesel generator room


17. Interior of Haddock Gallery showing the effect of prismatic lighting system


18. One of the 15 air-handling plantrooms


19. Roof showing cooling towers


20. Chiller plantroom facing east


21. Chiller plantroom north-east corner

Artificial lighting to the dealer floor is provided using specially-designed, high-frequency, linear fluorescent fittings incorporating both downlighting and uplighting elements to illuminate the intricate renovated roof trusses. To save energy, these luminaires, together with others on the first floor and outside, are controlled by a central dimming system according to available natural lighting levels. Artificial lighting is block-switched by a Building Management System on a time clock basis for other areas where there is little or no contribution from daylight. Natural and artificial lighting systems in many areas were designed and specified by the architect in association with Lighting Design Partnership.

The Building Management System controls the majority of plant, air supply and extract interfaces of temperature and humidity, optimization of start times, alarm functions, run times and monitoring of the sub-slab drainage system.

Conclusion

The integration of services and structure within the available spaces, with their unusual shapes and restricted geometry, at times seemed to approach the impossible during the design period, and this was coupled with the difficulties of determining design characteristics and properties of the original structural framework. However, close interdisciplinary collaboration eventually led to the realisation of the client's requirements. Practical completion was reached on 21 March 1989, and with it the resurrection of a grand old building to serve the modern era.

Credits

Client:
Citicorp Investment Bank Ltd.

Architect:
Richard Rogers Partnership Ltd.

Structural and services engineers:
Ove Arup & Partners

Acoustic consultant:
Arup Acoustics

Quantity surveyor:
Hanscomb Partnership

Management contractor:
Taylor Woodrow Management Contracting

M & E services contractor:
Crown House Engineering Ltd.

Photos:
7, 8, 10-12, 15-21: Peter Mackinven
2, 5, 14: Harry Sowden 4: Mike Taylor
6: Roy Smith 3: Ian Wattridge

Elan Valley Aqueduct

Keith Seago
Tony Jowle

Introduction

Built over 80 years ago, the Elan Valley Scheme was a major feat of engineering. Since construction, the aqueduct has conveyed water to Birmingham with minimum maintenance and without the need for major reconstruction.

In the mid-1980s Severn-Trent considered the time had come to carry out a major review of the condition of the aqueduct. The review showed the structures forming the aqueduct to be in good condition but nevertheless, 80 years on, it was time to carry out a renovation and upgrading.

History

Birmingham in the 1890s was a rapidly growing city with an ever-increasing requirement for a pure water supply. Demand had grown from 8.3M gallons per day to 16.5M between 1876 and 1891. There was an available yield of 18M gallons, but with peak demand of 22M the City Water Committee realised that problems were imminent.

For some time the city had had its eye on the Elan and Claerwen Valleys near Rhayader in mid-Wales which, they had been advised, were most suitable areas for storage of water. By January 1891 the Committee had received a report on the area from their consultant civil engineer, James Mansergh, which he concluded by stating 'that no better source could have been found or desired'.

James Mansergh was a Fellow of the Royal Society and Past-President of the Institution of Civil Engineers. He was an eminent railway engineer and had, some years before, while constructing the Mid-Wales Railway, recognized the enormous potential of the Elan area for water supply purposes. Others recognized the value of the area too and the Committee realised that if they were not prompt off the mark, then London might choose the area they had selected.

Editor's note:
As the works described in this article were designed in Imperial units, these have been retained throughout.

The City Council deliberated on the proposals during 1891 and finally approved the scheme in October. Immediate action was taken to promote a Bill in Parliament and, not without a struggle, the Birmingham Corporation Water Act received the Royal Assent in June 1892. This permitted the construction of up to six reservoirs in Wales and the necessary tunnels, aqueducts and service reservoirs at Birmingham, together with railways for the reservoirs' construction.

32 000 acres of land were required for the latter and their catchment areas, and provision was made for the replacement of a church, a chapel and a school, all of which were to be submerged. The works were constructed mainly between 1894 and 1904 when King Edward VII inaugurated the scheme.

A report to the Water Committee in June 1908, stated that the ultimate expenditure on the scheme was £5 884 918 for four impounding reservoirs and the aqueduct, comprising masonry conduit, tunnels and a pair of inverted siphon pipes, together with works at the Birmingham end. The dams were built by direct labour and the rest of the works under a series of contracts. The whole scheme provided Birmingham with a supply of about 75M gallons of water each day, delivered under gravity.

The scheme was augmented with the construction of a further dam between 1946 and 1952. The aqueduct's carrying capacity was increased by laying additional mains in the siphon sections in 1939 and 1961.

The original structures

The aqueduct runs for 73 miles from the lowest reservoir, just west of Rhayader, in a west to east direction past Knighton, Cleobury Mortimer, Kidderminster and Halesowen, to the outskirts of Birmingham at Frankley.

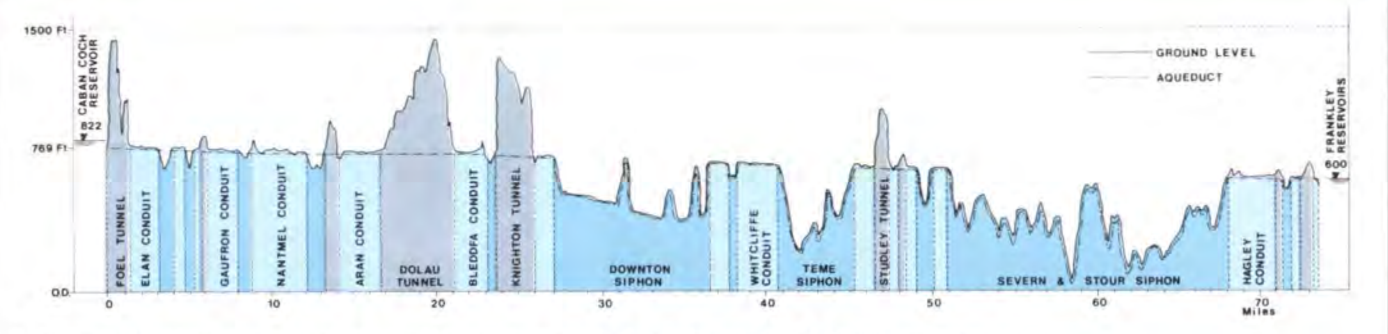
1. Map showing aqueduct route from mid-Wales to the outskirts of Birmingham

36 miles, 1248 yards of conduit are carried in tunnels, cut and cover, and special masonry constructions, the latter often being handsome arch bridges. The ruling gradients are 1 in 3000 for long tunnels and 1 in 4000 for cut and cover.

Where the aqueduct crosses valleys, the construction changes to pipework in the form of inverted siphons of 42in. and 60in. diameter cast iron and steel pipes. The total length of siphons is 36 miles and the ruling hydraulic gradient is 1 in 1760.

Chambers were built at the change from conduit to siphon sections, the 11 siphons on the whole aqueduct necessitating 22 of them. On the inlets they house control penstocks for automatic closure in the event of a burst siphon pipe. Several inlet houses have built-in overflow arrangements to divert the flow when problems such as a closed inlet penstock or overloading causes backing up in a conduit. Overflows emerge at streams and rivers and have their own structures to

2. Details of the 73-mile length of the aqueduct



3. Section, indicating various types of aqueduct construction and hydraulic gradient of 1:2300 approximately

reduce scour. Small brick structures, known as wellhouses, were built on 16 of the inlet and outlet chambers to house the controls and lifting gear for raising penstocks.

26 rivers and streams of a reasonable size are crossed by the aqueduct siphons. In the main the crossings are carried above flood level by self-supporting iron or steel pipe spans. The exceptions are three major steel structures over the Rivers Teme (twice) and Severn. One railway crossing was built in the form of a steel bridge over the main Worcester to Birmingham line at Hagley.

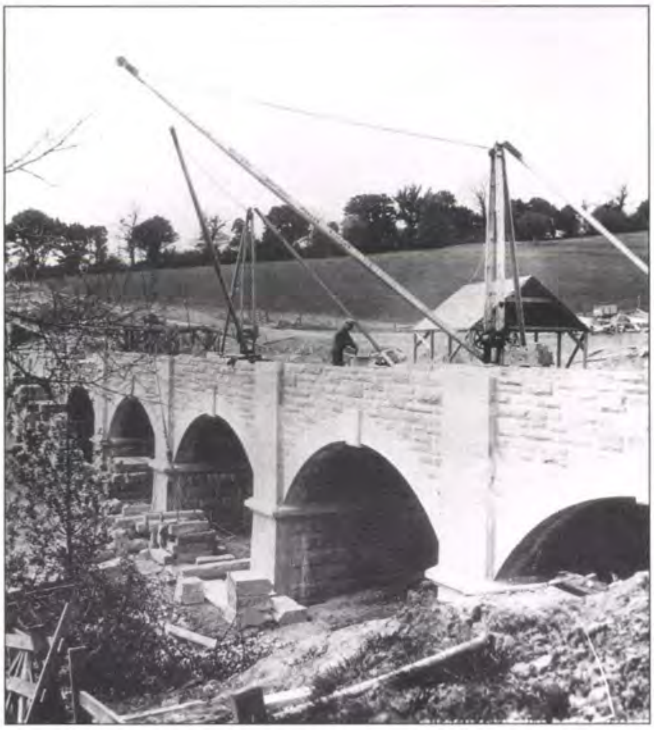
The Severn Bridge is 624ft. long overall, with five segmental approach arches in blue brick and stone. The river span of 150ft. comprises four segmental arched steel ribs 12ft. apart. The bridge is divided into three galleries across the width, once designed to take six mains but now used to house two 42in. in one gallery and two 60in., one in each remaining gallery.

There are several miscellaneous structures, including a special large-diameter tube forming a bridge over a farmyard on a conduit section of the aqueduct, and railway crossings with pipes in culverts below the tracks.

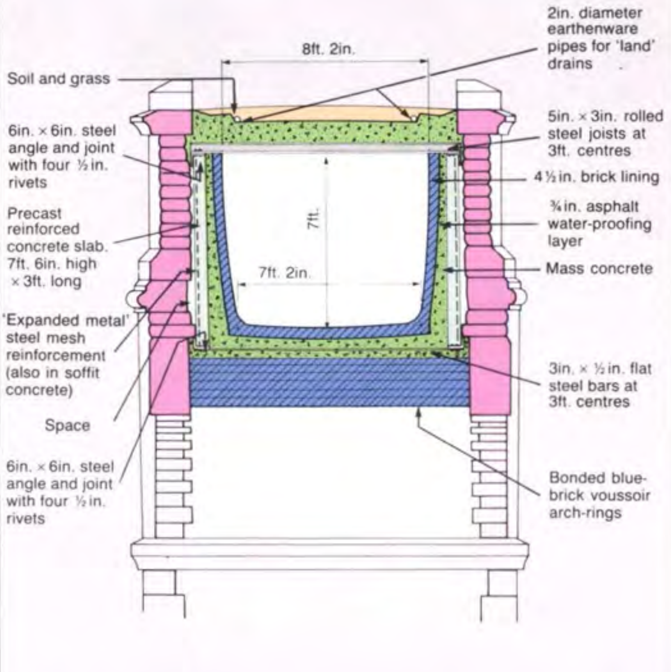
4. Hopton Inlet Wellhouse

5. Hopton Brook crossing, May 1902

6. Siphon pipe: Installation on Wye siphon, 1897



7. Hope Bagot Dingle:
Construction of a masonry arch structure



8. Aqueduct cross-section:
Conduit detail where carried on masonry arch supports

Key decisions for renovation and repair

Table of structures in the Arup brief

Major crossings Rea River Wolverley Stream Stour River and Canal Hagley Railway	Pipelines to be placed underground except at Rea where self-supporting spans altered or replaced.
Steel bridges Graham's Cot Steventon River Severn	For renovation
Minor crossings 16 structures	For renovation
Masonry structures 16 structures	For renovation
Wellhouses 16 buildings	For renovation
Siphon chambers six structures	For renovation
Other works 19 structures	Renovation and alteration of special structures: railway crossings, chambers, overflows, washouts.

The Elan reservoirs provide Severn-Trent Water with a high quality supply at a low unit cost. The water flows in the aqueduct by gravity with a difference in head of 169ft. between the top water level at Caban-Coch reservoir and the Frankley works on the outskirts of Birmingham. The average hydraulic gradient is 1:2300.

On average a daily quantity of 80M gallons is supplied to Birmingham and the Elan Scheme forms the major supply to the City.

The scheme, and therefore the aqueduct, are strategically very important to Severn-Trent, who consequently undertook in 1984 an initial appraisal of the structural condition of components and the security of certain parts of the works. The appraisal was carried out by Halcrow and a number of key recommendations emerged from their report for remedial works to structures.

Severn-Trent decided to divide the work between two consultants and, following submissions and interview, Halcrow were appointed to duplicate the strategically important Studley tunnel. Arups were appointed to the remaining structures, including the three major crossings of rivers and a railway.

Our work involves over 80 structures and ranges from inspection of the steel bridges and production of reports for the Authority's future maintenance and renovation work, to extensive alterations of major pipeline crossings (on the siphon sections). Broadly speaking, all this is designed to provide continued reliability in service well into the next century.

Arups' works

The project is best described in the categories of work as finally developed for contract or report purposes, but first a note on the logistics.

Our 80 sites were spread over the whole length of the aqueduct and some of them in remote situations. As inspections and appraisals progressed to the design stages, it became increasingly clear that it was not satisfactory to try to handle the work structure by structure.

Reviewing the situation with the client we decided, for the minor works, to divide the project east and west into Zonal 1 and Zonal 2. This change enabled efforts of inspection and design to be more concentrated and efficient. It meant that Zonal 1 works would comprise some eastern, masonry aqueduct alterations, repairs to minor pipe crossings and a few miscellaneous sites like railway crossings. From the Authority's point of view, provision of access to the sites was simplified by this reassessment.

Major structures and the steel bridges were considered site by site. The wellhouse renovations have now been divided geographically.

Major crossings

Each section of this part of the project involved relaying lengths of 42in. and 60in. diameter mains and making connections to the existing pipes as quickly as possible.

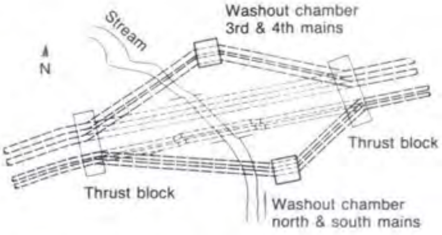
Connecting the pipes proved a severe constraint on the works and considerably affected the designs. At the connection points, the new lengths of pipe diverged from the existing straight lines. Such changes in direction, coupled with the pressures in the mains, produce forces which have to be catered for. At Rea, Wolverley and Stour, conventional concrete thrust blocks were provided. The design mass of these blocks was to a large extent dictated by water levels which reduced their effect due to submergence. In fact, high ground-water levels and the position of the blocks, usually underneath the direction change points, posed considerable problems. Contractors had to allow for temporary supports to the existing mains which were live and for laying as much as possible of the new pipelines before any one main was taken out of action in the one week connection period. Usually no more than one pipe at a time could be disconnected from supply. Connecting all four pipes at once would have produced an unacceptable shutdown of the aqueduct.

9. Rea River Crossing: Towards the completion of construction in 1902. Three 42in. pipes were installed at this stage.

10. Rea River Crossing: The three old pipes are under the canopy on the left of the picture, with work proceeding on installation of the new 60in. main, December 1987.

Wolverley

All four mains required diverting and laying below the Wolverley Stream at this site. In order to make the connections one at a time and keep pipelines to be laid in the connection period to a minimum, a diamond-shaped pipe configuration was developed. Anchorages were built beneath the existing pipes at the bend positions and had to be ready in time for making the connections. Bends were strapped to the thrust blocks already cast and the whole resistance to thrust was designed for the operational pressure of 250lb./in.².



11. Wolverley Crossing: Showing the diversion arrangements for removal of the original stream crossing. The mains were diverted in the order 4, 3, north and south.

Rea

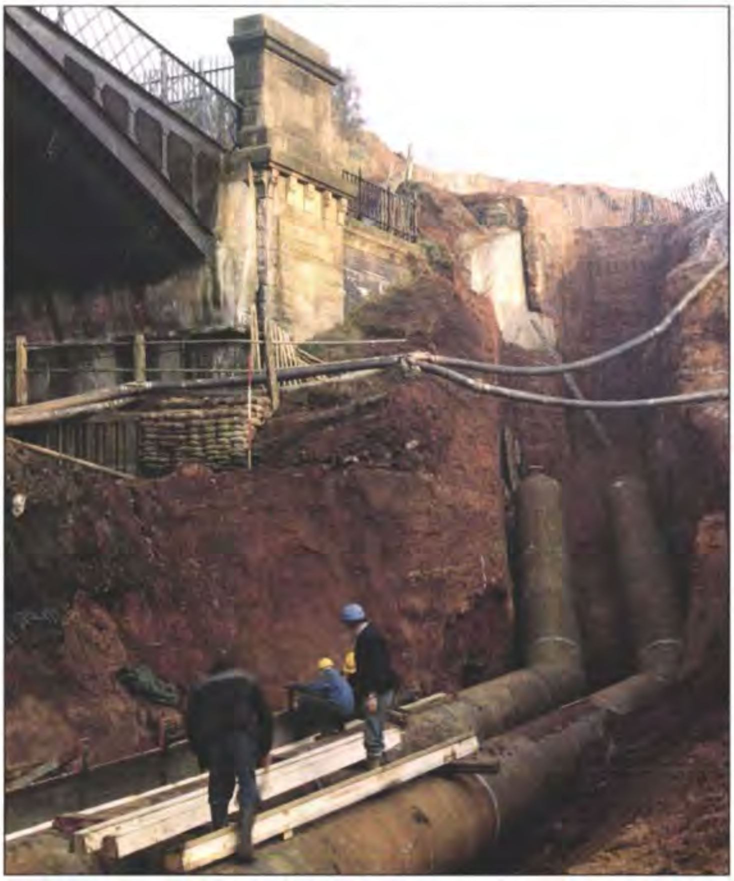
This part of the project required the replacement of the mains which bridged the Rea River as self-supporting spans. The original configuration had in-built hydraulic restrictions and the two old 42in. mains were bady corroded. After considering the cost of putting this crossing underground, it was concluded that the most effective solution was to replace the pipes as bridges. The opportunity was taken to extend the bridge abutments and introduce a new 60in. diameter pipe whilst abandoning one 42in. pipe, thus improving the hydraulics. The spans were designed as self-supporting pipes, 54ft. long in welded steel.

Stour

On this contract, two 42in. diameter mains had to be relaid underground and beneath a river and a canal; 60in. diameter pipes were already below ground. The existing structures carried the 42in. mains over a canal, across a flood plain and over the Stour River. The new steel pipes suitable for the pressure of 250lb./in.^{2} were laid alongside the existing structures, concrete-surrounded for corrosion protection. Both mains were connected at the same time and thrust from the bends was catered for by concrete blocks constructed below the connection points. The bends were anchored to the block using mild steel straps.

12. (left)
Stour Canal Crossing:
The canal bridge on completion in 1902. Diverted 42in. mains were laid left of the structures below the canal.

13. (below)
Stour Canal Crossing:
Twin 42in. mains being laid beneath the bed of the canal which was temporarily dammed, December 1987.



14. (above)
Hagley Crossing:
Welding 60in. pipes during the outage for connection of the new diverted fourth main,
December 1988.

Hagley

Four siphon pipes of 42in. and 60in. diameter, operating under 160lb./in.^{2} pressure, crossed a railway cutting at this site. Three were on a steel girder bridge with the fourth, installed in 1969, self-supporting.

The new pipes, five in all to include a spare 42in., had to be laid beneath the railway tracks and some difficulties were encountered in negotiating with British Rail. The Board eventually accepted our proposals to carry out this work in open cut rather than by provision of tunnels or culverts. There were doubts about whether all the work necessary to lay the five pipes could be carried out in the 54-hour period allowed for in the Possession. However, the contractor did achieve this with time to spare and British Rail's only involvement in the Possession work was to take up and relay the tracks. Prolonged negotiations with British Rail eventually yielded a date in 1988 when the line could be closed. The period of planning the work was a most difficult time because the Possession had to be fitted into Severn-Trent's requirements for the pipeline outages, and the pipes had to be taken out in a certain order.

Each connection was made by laying as much new pipe as possible up to the old 'live' mains before the cut-off period. At the cut-off, lengths of the main were removed and new pipes fitted using flexible couplings.

The anchorages are interesting. We adopted a different approach here because the water level problem did not exist. Anchorage was provided by designing tension straps from the bend position along the line of the old pipes. This was achieved by fixing steel anchor strips to the bends and connecting these to reinforced concrete beams running alongside the existing pipes. The design intention is to use the mass of the pipes, water and, where it exists, concrete surround of the existing pipes, to resist the pipeline force (of 200 tons in the case of a 60in. pipe) by friction between the pipe surround and rock. This friction can be fully developed as the water table is low. The 60in. mains were already concrete-surrounded so the tie beams were connected by shear connectors. A new surround to the 42in. mains formed the tie beams for these mains.

Strapping across the flexible coupling removed the flexibility but this was not important. The coupling was provided to allow for inevitable inaccuracies in fabrication of the pipes and setting out.

Zonal works

These consisted of masonry aqueduct structures, minor pipe crossings and a number of special structures.

In consultation with Arup R&D, and as a preliminary to this work (and to the steel bridge renovations) we had let an investigation contract, which had provided information on the masonry structures generally and four in particular that seemed to be in the worst condition, together with materials information on two minor pipe crossings. The inspection reports showed the masonry structures to be in excellent condition and our main recommendation to the client was for improvement of the conduit roof covering. This took the form of a waterproof layer on top of the concrete surface, with a limestone covering to provide an extension of the generally alkaline environment which had protected the structural steels so well over the years.

Pipe banding

There was a main thread of concern in all our investigations of the pipe crossings. 42in. diameter steel pipes had been used at most of the crossings, self-supporting and otherwise. The method of fabrication in the 1890s was a boiler-making technique, with short lengths of pipe joined together at the factory with wrought iron rivet bands. We saw considerable evidence that the rivet heads and the iron bands were corroding and we regarded these bands as the most likely sites for failures to occur. Our design for their improvement, developed with Arup R&D, involved fixing a steel strengthening band, designed to be equivalent to the wall of a pipe. This would fit as closely as possible to the outside diameter of the rivet heads, fixed externally while the main was under operating pressure. In order to ensure that the rivets which did not touch the steel band were held in place, the annular space would be grouted to provide structural strength and waterproofing. A steel former was used in a 'top-hat' shape to provide a mould for the grout.

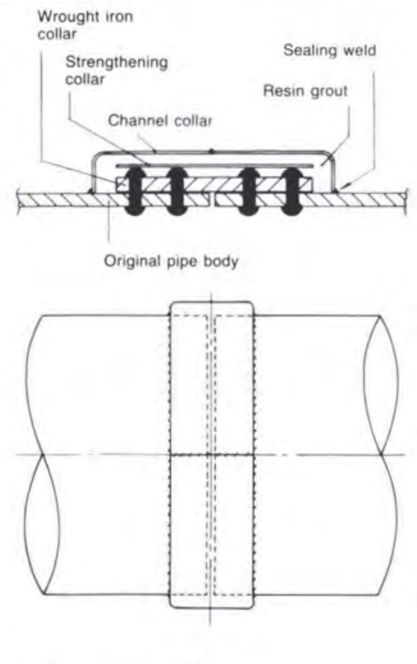
The whole device was extensively tested on lengths of mains recovered from demolition work at one of the major crossing sites. With an appropriate grout seal, one of the test pieces withstood twice the working pressures. Four resin grouts were tested and Sika-Inertol *Sikadur 42* epoxy resin gave the best performance. We learned from the trials that the bleed header pipe should be of adequate diameter, provided with a small reservoir, and that the resin injection time should be extended to a few minutes after the annular ring appears completely filled.

Some destructive testing was carried out by cutting up pieces of the rivet band. The slices obtained were visually examined and showed graphically why some grout systems failed by inadequate filling. One slice in particular illustrated how effective the technique could be with the *Sikadur 42,* applied in the correct fashion.

Severn-Trent have taken our recommendations and designs and are carrying out the works themselves using their Direct Labour and Construction Department.

Steel bridges

The three steel bridges were examined by our team and Arup R&D. Renovation and maintenance schemes were developed for the steel structures, the river banks and abutments. The results were presented in illustrated reports, one of these being a guide to indicate the sort of maintenance activities required.



15. Rivet band detail:
Showing design for strengthening
the old steel pipe joint detail.

Wellhouses

Work on the wellhouses comprises refurbishments and minor alterations to provide a satisfactory environment for the installation of new telemetry equipment.

Summary

The Elan Project has been most interesting and it has demanded of us appropriate reaction to changing requirements during the development of the scheme. The alteration of the pipelines and working to tight deadlines for making connections dictated the way the engineering was carried out. The solutions to the pipeline thrust problems required much thought but proved satisfactory in construction.

Input by Arup R&D and the London Water Group has been most valuable, underlying again Arups' strength in bringing together all our skills on a particular project.

A fringe benefit of the work has been a greater appreciation of the works of the Victorian engineers who produced a scheme and structure that have lasted 90 years and now will work well for another 90.

16. Band detail: Test piece sliced through after grout injection and tested to twice working pressure.

17. Hopton Brook repairs: Strengthening arrangement installed by Severn-Trent, winter 1988-89.

Credits

Clients:
Severn-Trent Engineering
Severn-Trent Water Authority
Consultants:
Ove Arup & Partners
Sir William Halcrow & Partners
who carried out the pre-scheme appraisal
Contractors:
Rees/Hough (Civil Engineering) Ltd.
(Stour Crossing)
Biwater Construction Ltd.
(Wolverley Crossing)
Wrekin Construction Ltd.
(Rea Crossing)
George Law Ltd.
(Hagley Crossing)
Photos:
4: Courtesy of Sir William Halcrow & Partners
5, 6, 7, 9, 12:
Courtesy of Severn-Trent Water Authority
16: Chris Barr. 17, 18: Simon Smail
10, 13, 14: Eric Kirk

18. River Severn Bridge:
General view of 150ft.
span steel crossing,
carrying four siphon pipes.

Heroes' Acre

Architect: Montgomerie Oldfield Kirby Denn Wilson

Stuart Perry

It would be fair to say that with the possible exception of Victoria Falls, Heroes' Acre has the highest number of visiting dignitaries and is always on the itinerary for guest Arupians. The shrine is the memorial to commemorate the struggle for Zimbabwian Independence. It is located about 5km west of Harare.

The complex of piazzas, curved terraces and linking stepped areas which form the memorial has been constructed to the design of a local firm of architects, Montgomerie Oldfield Kirby Denn Wilson. It is based on a concept provided by a team of North Korean sculptors who were commissioned by the Government of Zimbabwe to design the central and mural bronze sculptural pieces that have now been incorporated in the final scheme. The architects were asked to use Zimbabwe granite as the primary finishing material.

Ove Arup and Partners were appointed as consulting civil, structural, mechanical and electrical engineers in 1980 when final design work commenced.

Formal access to Heroes' Acre is ultimately along a straight 1km approach leading directly to the ceremonial entrance and on to the Place of Assembly. This is the lowest major part of the complex and forms a saddle between two rocky outcrops, the summits of which are on an approximately north/south axis. The memorial is symmetrically placed about the same axis on the north face of the southern outcrop and opposite the spectator seating on the northern outcrop. Spectators thus overlook the Place of Assembly, beyond which is the central piazza. The piazza is flanked by the twin horizontal features, 15m long and 9m high, which carry the Heroic Murals on their inner faces and a bronze sculpture of the Zimbabwe Bird atop the leading edge. The sides of the features are clad in red sandstone facings and the plinth and leading edge in polished black granite.

Dominating the central piazza is the three-figure central sculpture, approximately 9m high on its plinth. Behind it, and defining the southern perimeter of the central piazza, are the curved ascending folds of the buttressed wall at the centre of which is the Tomb of the Unknown Warrior. Ascending each side of the curved wall are the two symmetrically balanced curved legs of the grand staircase which terminate centrally to form its divided stairway. On the outer sides of the curved legs, three symmetrical terraces containing 60 graves embrace the curved form of the outcrop. The grand staircase ascends to the summit piazza from which rises the 42m tower with its viewing balconies and Symbolic Flame. The flame is of a geometric design, illuminated at night by internal neon lighting to give the appearance of a flame.

Landscaping has played a significant role, the general approach being to maintain the indigenous bush environment as far as possible and where the edges of new work impinge, to reduce the terrain to bare rock and introduce pools of planted grass and Bougainvillaea, thus creating a transitional area of colour and contrasting sophistication. The two parking areas provided for buses and cars are designed to preserve as many trees as possible and retain the natural beauty of the area.

Consideration has been given to the design and installation of the electrical services, of which lighting forms the major component. Spherical street lights have been installed along the ceremonial way and the access road to the summit piazza; recess light fittings illuminate the Tomb, terraces, grand staircase and Place of Assembly. The curved wall, horizontal features, tower and adjoining areas are floodlit.

Further works are being undertaken at the entrance to the complex, the most striking of which is a 15m high, four-legged portal frame supporting a 20m high flag pole. Two ablution complexes have also been included in the development.

The engineering challenges posed were varied and interesting. One of the more complicated structural engineering elements was the spectator seating, which in isolation might be seen as the least impressive part of the Memorial. The axis and designed slope of the grandstand were dependent on the axis of the Memorial itself, and the contours of the northern (spectator) outcrop were not entirely in sympathy with this design. The final structure incorporated a combination of in situ, precast and prestressed concrete work.

The seating, for approximately 2000 persons, covers 3000m^2, a tenth of which is on compacted fill with the remainder suspended at between 2m and 6m above the natural hill slope using a combination of in situ and prestressed concrete. A number of finishes for the seats were investigated; synthetic turf as well as grass and timber were rejected in favour of precast concrete.

Various structural schemes were considered for the tower bearing in mind the possibility of vandalism, the need to fix granite cladding, avoidance of corrosion by eliminating exposed structural steel, and speed of erection.

The tower had to be completed by Heroes' Day, 11 August 1982, construction having commenced in January. It is octagonal in section, reducing from 5.3m across its base to 2m at the cap which forms the base socket for the Symbolic Flame. Two viewing balconies are incorporated, the lower cantilevering 5m from the face of the tower and the upper cantilevering 3m.

The combination of in situ concrete up to 10.5m and precast concrete clipped to a structural steel frame was adopted. This allowed precast units to be delivered as required, with scaffolding and formwork above 10.5m being rendered unnecessary.

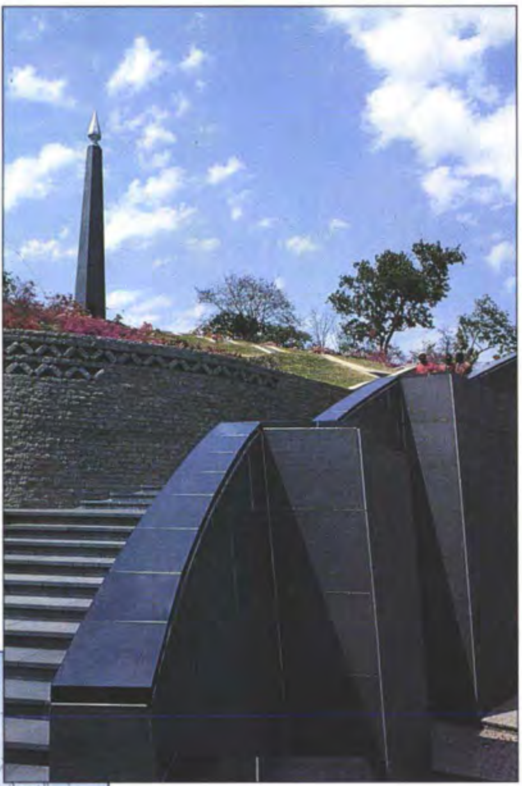
The central folded wall passes in a curve behind the main sculpture and rises to 7m with the face being stepped 1m every 3m and sloping backwards at 1:10, resulting in the panels being curved in two directions. The complex wall geometry was constructed using 230mm hollow block wall panels reinforced horizontally and vertically within a reinforced concrete frame.

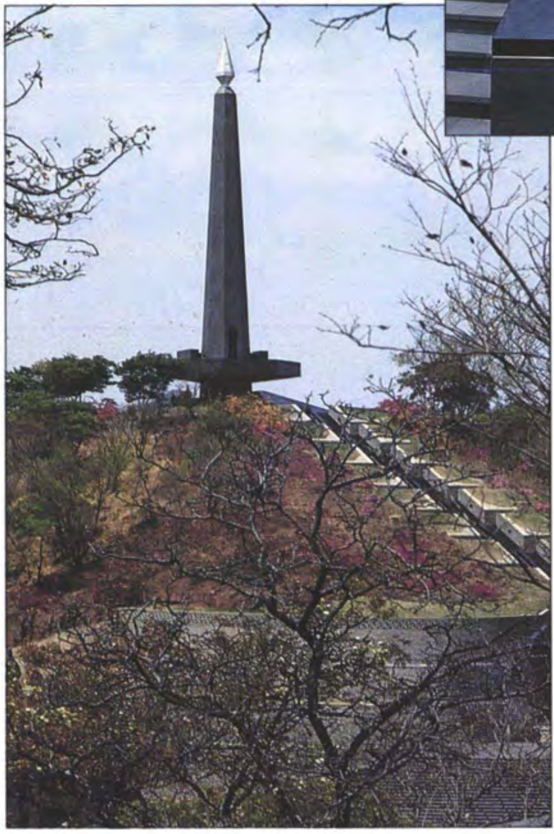
Granite cladding of the various faces prompted the formation in 1983 of a new company, a division of the main contractor. The alternative would have been to ship local granite out of the country for processing and return it as finished. This was prohibitive because of the foreign exchange involved. Zimbabwe now has a facility for processing black granite, both for the local industry and export. it also develops local marble for the architectural profession. The granite is of a high standard and uniform colour and is exported throughout the world.

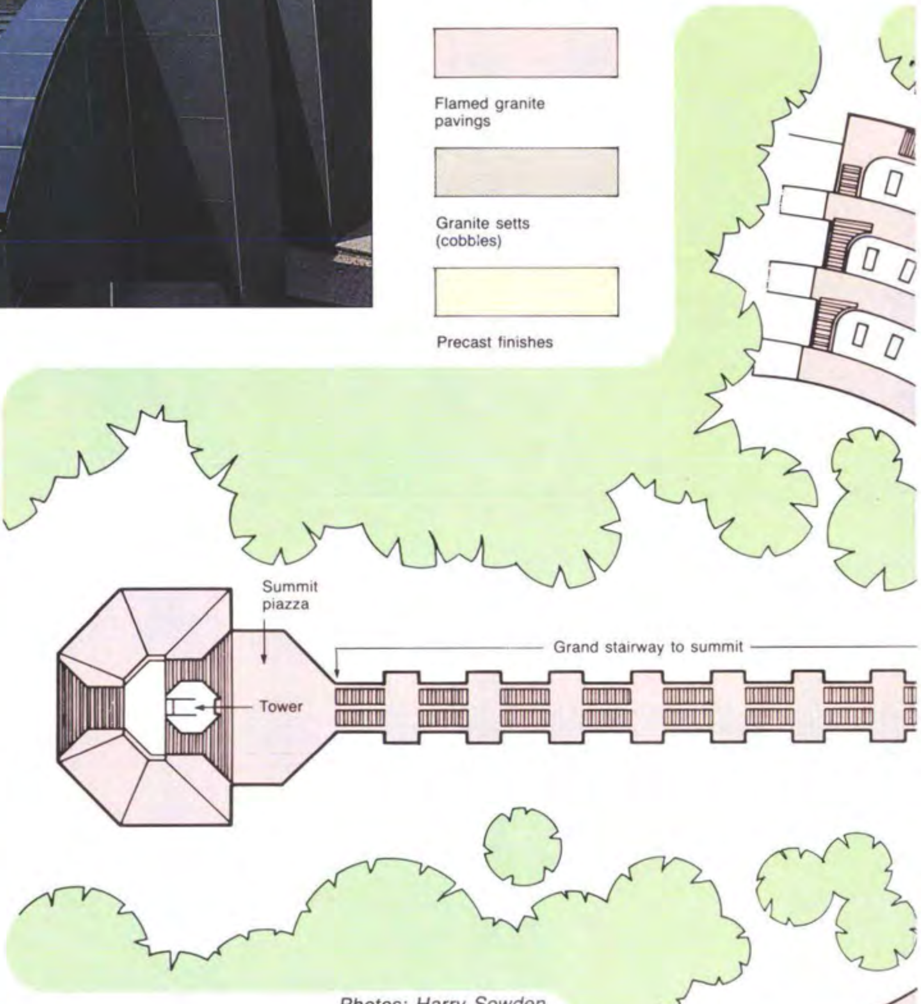
We were asked to advise on the vertical fixings of the granite cladding as well as on the granite pavings and setts as nothing of a comparable nature had been constructed in this country. We had no experience of granite finishes and were very grateful for Arup R&D's assistance. Austenitic stainless steel type 304 fixings, which would give the long life required of a monument, were used with stainless steel shims and washers for adjustment. The tower cladding was of 750mm high × 40mm thick granite with the

quoines standardized where possible and the infill panels adjusted to suit the tower taper. Granite finishes were either polished or flame-textured, achieved by drawing an oxy-acetylene descaling head across the granite face. This is a skilful operation as slabs can easily be broken by heat or the finish distorted. In Europe this is carried out by machines carefully set to the correct distance and speed of coverage. In Zimbabwe, however, it was done by hand. The polished granite finish was achieved by using normal modern semi-automated polishers.

The small paved areas were covered with flamed textured granite slabs 800mm × 450mm × 35mm thick, and the larger areas paved with 100mm × 75mm thick granite setts (cobbles) set into a 3:1 sand/cement





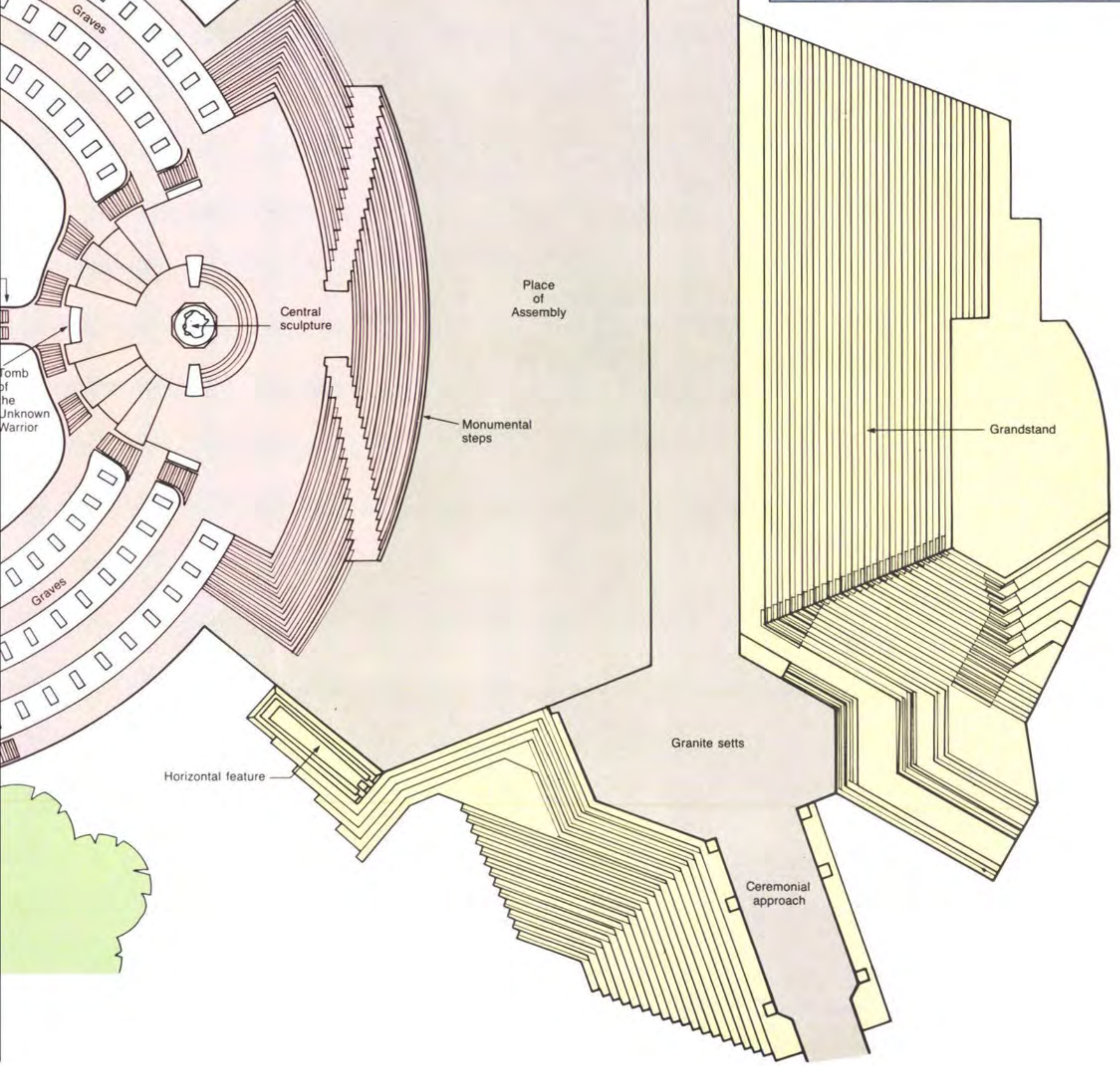


Photos: Harry Sowden

mix. The use of granite setts was on our recommendation as the original requirement had been for 35mm thick granite slabs throughout. In discussion with Arup R&D it was agreed that the potential for failure in these large areas using granite slabs was great and therefore the thicker, smaller setts were accepted by the architect and client as being the correct solution.

The project is due for completion this year, nine years after commencement. As a high profile development it always creates interest and discussion and is one of the more unusual projects we have undertaken in this country. Looking at the finished result it is remarkable how closely it resembles the original artwork, which is perhaps because it is in essence a sculptural work rather than a functional building.

Credits:
Client:
Government of Zimbabwe
Project architect:
Ministry of Public Construction and National Housing
Architect:
Montgomerie Oldfield Kirby Denn Wilson
Civil, structural, mechanical and electrical engineers:
Ove Arup & Partners
Quantity surveyor:
Hawkins Leshnick Pridgeon and Veale
Main contractor:
John Sisk and Son (Pvt) Ltd.
Main contractor (roads):
Tarphalt Paving (Pvt) Ltd.
Granite finishes/subcontractor:
Zimbabwe Stone Development
Electrical subcontractor:
William Steward (Zimbabwe) (Pvt) Ltd.



Passive solar design

John Campbell

Introduction

The idea of using solar energy has been with us for many years. Vitruvius, an architect of the first century BC, was probably the first professional to write about it, but he was certainly not the originator of the idea, his writings being simply an expression of the good architectural practice of the time.

In more modern times, following the Industrial Revolution, cheap, readily-available sources of energy affected the economics of design and as a result, buildings steadily changed as designers explored the extent of their new freedom — in some cases exceeding its boundaries.

By the late 1960s, however, it was already becoming obvious to some people that energy resources were finite and that some action had to be taken to reduce our dependence on fossil fuels before it was too late. Another factor which had previously been unrecognized (outside the field of science fiction) was the greenhouse effect. The latter was starting to look like a distinct possibility by 1970 and reduction of fossil fuel consumption might therefore have a dual benefit.

In fact it has become increasingly clear that if we are to have a completely clean source of energy to keep us going until fusion power becomes available, then the options are limited: fossil fuel is causing concern because of the greenhouse effect and the lobby against present nuclear power is still strong. Passive solar energy utilization is one of the other options.

Investment in energy conservation, however, continued to be a very low priority with governments until 1973, when the Yom Kippur War took place, radically affecting the supply of oil to the West. Energy ceased to be a long-term issue and became a political one.

The UK Government, in common with many others in the West, took a positive stance towards energy research. Initially, as they felt their way forwards, most of the expenditure was directed towards conservation, which meant using less of our current resources and was not concerned in any way with the type of fuel used. The next area to be investigated was that of alternative fuel sources with solar energy in the forefront. At first, most of the work was on active systems; in fact, these were the only systems that could be considered but, as an understanding of the subject developed, it was realised that improvements to conventional design practice could make use of solar energy for heating, without the addition of another consumer of energy, such as a pump, to move it. This was promptly dubbed 'passive' solar utilization and the word 'active' applied to all systems that did not fall within this type. Research concentrated on using alternative energy sources to replace conventional ones, with solar collectors providing domestic hot water, heating and in some cases even refrigeration.

This was the pattern in most of the developed countries and some very interesting and enterprising demonstration projects were completed which incorporated not only solar heating and hot water but also solar-powered refrigeration. By and large, however, whilst these projects worked and demonstrated technical feasibility, they were difficult to justify on a cost-in-use basis.

The result was that more and more of the money available for research in the renewable energy field was channelled into passive proposals.

It is fair to say that one or two leading architects had already moved in this direction before any policy changes took place, and some of the leading examples of 'passive' design were constructed before the name was first coined. The big difficulty is that whilst we know the buildings use less energy that a conventional building, we cannot be certain which features are actually contributing and which are not actually giving us much benefit. There is very little historical data to assist in quantifying the benefits that can be obtained from the different passive measures that can be applied to buildings.

The study

Statistics do not really work very well unless you have a very large sample, and the way people use buildings can affect the energy consumption in them a great deal. For that reason, statistical analysis is not much use because the size of the passive solar sector at the moment is not adequate to give us reasonable figures. We recently completed a project for the Department of Energy in which we examined these points and that project is discussed here. The investigation involved eight different types of non-domestic building. We asked eight leading architectural practices each to design one of these types with which they were familiar and which had a 'standard' brief. At the same time, we asked them to incorporate passive solar features into their designs which were then compared with others — existing buildings as well as theoretical solutions — offering traditional responses to the same brief. The comparison was made using computer simulation to carry out thermal analysis and traditional cost analysis techniques to obtain capital costs variations between the two solution types. One point to note is that although this was only a desk study and the designs would probably not be built, we were keen that they should be practical for comparison purposes. We therefore asked various bodies to co-operate as 'pseudo-clients' for each design to ensure that it was as practical as its traditional counterpart.

It was possible to carry out sensitivity analyses then on the different benefits to be obtained from each feature. In other words, you could increase the size of a window, look at the costing change and look at the energy benefits. In addition to the computer analysis and the quantity surveying, the pseudo-client involved also commented on the passive design at various stages and made sure that it was at least as marketable as the traditional design. In other words, it would be very easy to come up with a design which would save energy but might not be acceptable to the general public.

We felt at the end of the exercise that we had developed a justifiable working methodology that enabled us to assess the relative performance of a passive solar building whilst eliminating the variations in occupant use and their effect on energy consumption. At the end of the contract we made visual presentations of what had been achieved and what still had to be done. The first quantified the solar contribution for architectural practices, who may or may not have a knowledge of passive solar design, and encouraged the use of solar design to reduce energy consumption.

The second dealt with strategy, how we could go about getting these ideas across to the architectural practices that we were dealing with. The aims of the design studies were obviously to produce effective passive solar designs, assess the performance, improve the methodology and, if we could, in the long term also accelerate the acceptance of those techniques amongst the industry generally.

The factors affecting any building are that a certain group of external gains contribute to its heat, making it comfortable in winter by providing warmth, but sometimes causing overheating in summer. These are basically the diurnal range where the graph shows the temperature changing through the day and direct sunshine (Fig. 1).

Inside the building some heat gains also take place — lighting, people, machinery — and these also can contribute to warmth and in some cases again overheating (Fig. 2). Comfort is rather difficult to describe at times, but in Fig. 3 we have shown two lines. One of them is the point at which a percentage of the population would be uncomfortable in winter dressed in normal winter clothing, and the top line between the green and the yellow is the level at which lightly dressed people would be starting to feel excessive discomfort in summer. The averages are about 19°C in winter and up to 27°C in summer. The yellow band shows the increase in temperature in an average room due to the internal heat gains taking place in a normal office space (Fig. 4). If you superimpose the two, a green comfort zone becomes visible (Fig. 5).

Figs. 6 and 7 show what can be obtained by using passive solar techniques in the right case. Shade above windows (Fig. 7) admits the sun in winter and cuts it off in summer so that the amount of heating can be reduced and in some cases the overheating eliminated completely at the top. That is the objective of the exercise.

The features that we examined in this particular situation were:

(1) Orientation (in other words, which way the building faces relative to the north)

(2) Built form (whether we use a longitudinal building, a hollow square or a tall thin structure with atria)

(3) Fenestration (the size of windows on the outside of the building)

(4) The window shape (tall, thin windows in the Georgian style, or short and wider)

(5) Shading (putting overhangs above the window so that the sun can be cut off in summer and still admitted in winter)

(6) Perimeter daylight (windows round the exterior)

(7) Direct gain (in other words, letting the sunshine in to provide heat as well as light)

(8) Natural ventilation for cooling

(9) Building weight (massive buildings will have a great deal of thermal inertia and do not overheat as easily)

(10) Atria (the modern concept of an area with a glazed roof across the top)

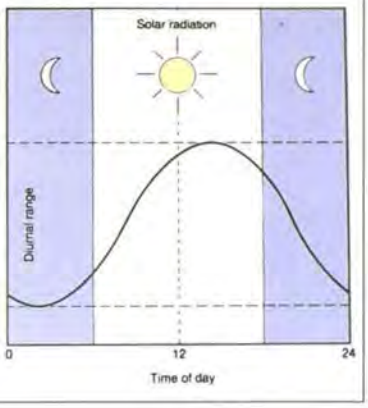
(11) Conservatories (glazed areas built into the outside of buildings)

(12) The Trombe wall (a French concept of a glazed area with a solid wall behind it, facing south). We found in the study that these always saved energy, but because it was a straight addition to the building cost, the capital cost was always more than could be justified by the energy-saving.

Cost-effectiveness was calculated by comparing the designs in terms of the energy saving per year, and the capital cost of the solar features to achieve that saving. Using various discount rates and time horizons for return on the capital investment, the study drew conclusions as to whether the savings achieved were in fact cost-effective for the majority of building clients, for only some, or for very few. The dotted lines on Fig. 8 could be read as a five year return on investment, a 10-year return and a 15-year return. Of the eight building types studied, all saved energy by passive solar means: the light industrial building, the nurses' hostel and the low rise

Two factors affect internal environment

- Diurnal range
- Solar radiation



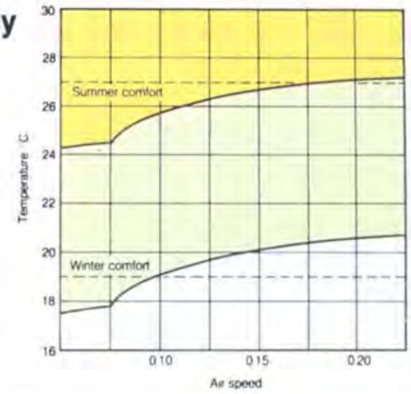
1

Other heat gains

- Occupants
- Lighting
- Equipment

2

Working efficiency requires environmental comfort

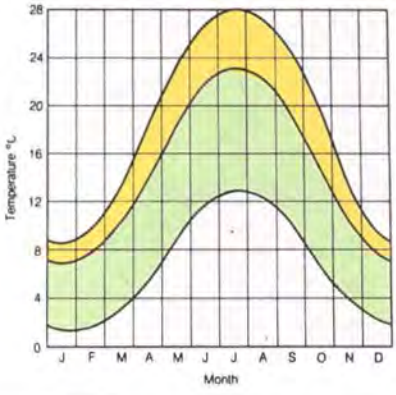


3

Combined effect

🟨 Heat gain

🟩 Diurnal temperature over seasons



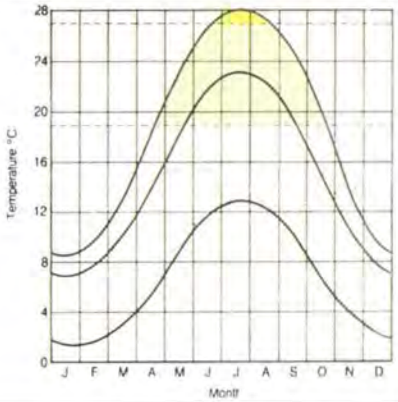
4

Comfort zone: temperature

🟨 Cooling required

☐ Heating required

☐ Heating not required



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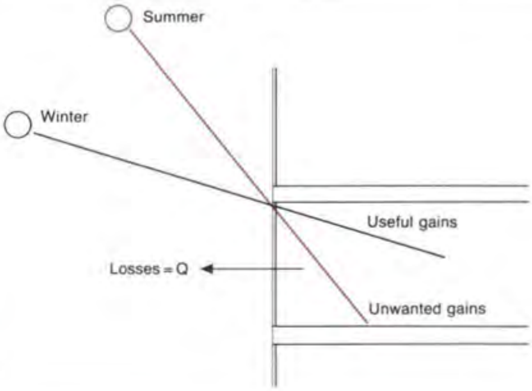

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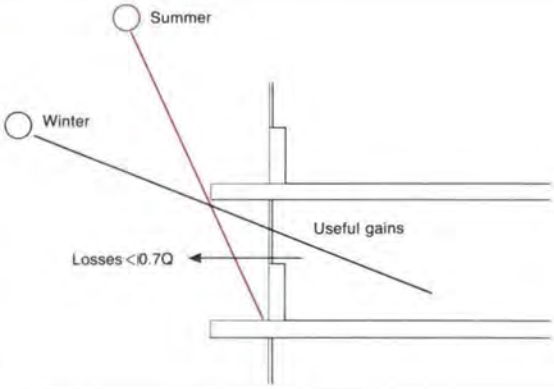


7

Figs. 1-5 show diurnal and seasonal effects upon the environment by solar radiation.

Figs. 6-7 show effects obtained by passive solar techniques.

office were marginally cost-effective; in the hotel, the do-it-yourself superstore and the medium-rise office, the energy savings did not appear to be achieved cost-effectively although there were other benefits in terms of comfort amenity.

The results

Results for the eight designs were as follows:

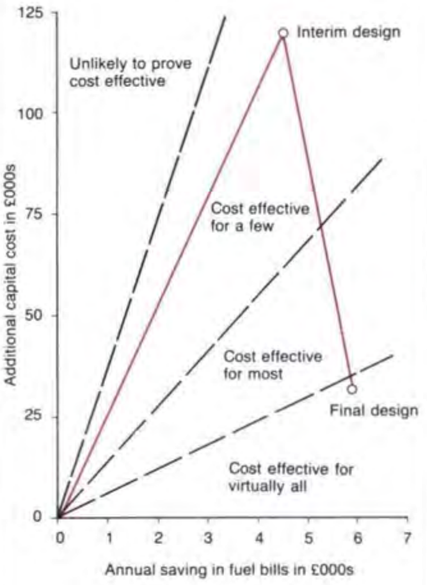
(1) The light industrial building had savings on both heating and lighting

(2) The sports hall had a marginally increased heating load but some saving in lighting, electricity being more expensive than gas

(3) The nurses' hostel had a major saving in heating and a slight extra on the lighting (incidentally, this was theoretically located in Scotland)

(4) The school retrofit had already had some work done to it to make it energy-efficient, but not particularly passive solar. We took that design in terms of retrofit and it was considered marginally cost-effective, but as there was a 20% increase in the number of pupils accommodated, it actually showed considerable savings per pupil.

(5) In the medium-rise office block substantial savings were achieved in energy terms



8. Cost effectiveness findings

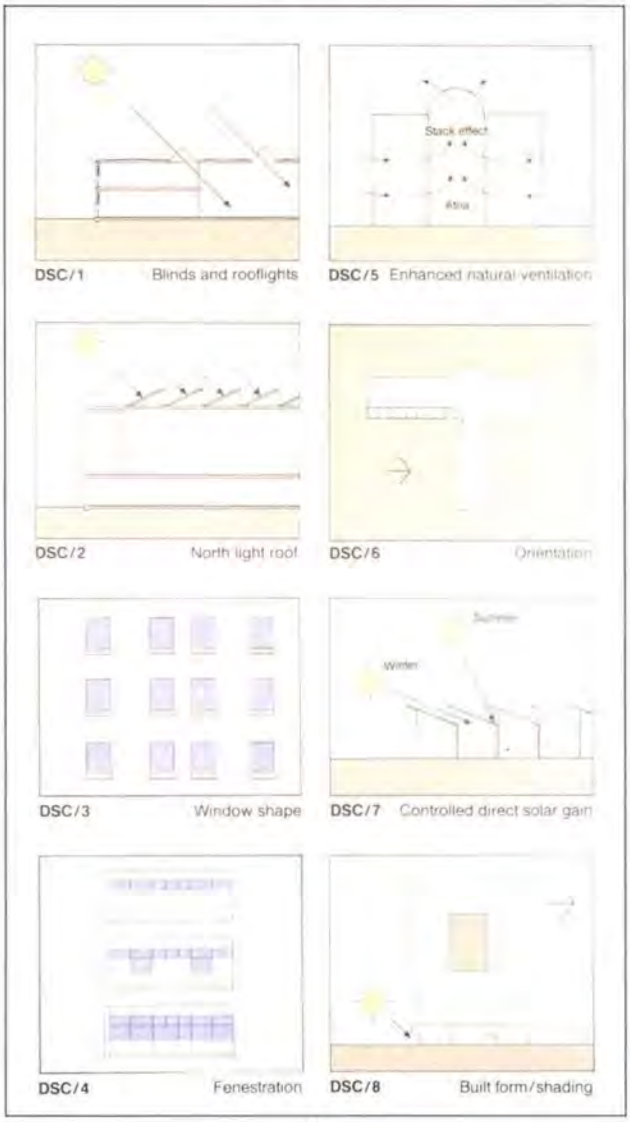
Key solutions

DSC/1
Light industrial building: roof lighting for daylighting and some heat.

DSC/2
Sports centre: the north light approach avoiding the admittance of too much heat; people generate plenty of their own in this type of building.

DSC/3
Nurses' home: window shape plus a percentage of glazing on that particular area; the architect for this Scottish project drew our attention to the fact that, having spent a lot of time computing cost-effectiveness, he had ended up with a solution that looked traditionally Scottish.

DSC/4
Secondary school (retrofit): this shows the types of glazing solutions that were examined for the exterior perimeter refurbishment.



DSC/1 Blinds and rooflights
DSC/5 Enhanced natural ventilation
DSC/2 North light roof
DSC/6 Orientation
DSC/3 Window shape
DSC/7 Controlled direct solar gain
DSC/4 Fenestration
DSC/8 Built form/shading

DSC/5
Medium-rise office: sun shines into the atrium and warms air, which then rises and draws air into the rest of the building; thus avoiding the need for air-conditioning.

DSC/6
Hotel bedroom block: this solution uses orientation to a large extent, locating the hotel bedrooms so that they get the conservatory spacing in the optimum direction.

DSC/7
DIY superstore: direct light was allowed into the store through south-facing glazing, but with sufficient cut-off to prevent the sun shining directly into the building and overheating it in summer; both winter and summer angles are shown on the diagram.

DSC/8
Low-rise office: this shows the courtyard-type solution.

9.

but the actual capital cost of providing the solar heating was quite high. The main feature of this building was the introduction of atria which improved its amenity value and quality. The client said that this building should be commercially attractive and have a high profit rental, so in its design it was successful.

(6) In the hotel bedroom block the solar gain during the day was at a time when the bedrooms were unoccupied and there was no demand for either heat or light. Because of that we looked at below-ground rock storage for the heating recirculated air, but this was shown to be uneconomic.

(7) The do-it-yourself superstore was by its nature a very simple building, not much more than a shed in effect, with a very basic specification, so that when one started incorporating passive solar features the cost of doing so was quite excessive.

(8) The low-rise office block did require some additional energy for heating but this was set against a large saving in lighting, reduced by optimization of the windows and incorporation of a special type of roof light.

These studies are fully documented in reports which we and the other consultants working with us have prepared. Copies of all these documents are lodged with the Energy Technology Support Unit.

Certain guidelines could be drawn from these studies. If heat gains are high, heating is probably unnecessary in both summer and winter; an office building with high density of equipment can provide nearly all its own heat from internal sources, so under these circumstances daylighting only is required from the sun. If you have a building with low gains, then not only is lighting needed all the year round, but heating as well in winter.

These guidelines were used in different examples. How do you get daylight access into a low-rise building? If it is single-storey, shallow-plan, it can be admitted through the windows at the side of the building. If it is deep plan, the solution of roof lighting for the centre with the Georgian-style tall, thin windows at the perimeter, works very well. The Victorian north light roof was a very good example of how to let light in without heat, because of the problems they had to overcome without being able to resort to air-conditioning. In multi-storey buildings of shallow plan, again side windows can be used for daylighting. Low-rise, deep-plan buildings can have courtyards; if they are high-rise, atria can be a solution. Fig. 9 shows examples of the different solar methods that were used.

Conclusion

Finally, achievements. On all eight of the buildings a high quality of design had been achieved by architectural practices with whom we worked, which gave good commercial credibility to the results. (There was little point at all in getting good energy results if the buildings themselves were not credible afterwards.) The architectural practices successfully exploited passive solar techniques and all eight felt that they would use this approach for future projects. We felt that we had developed some quite important guidelines, that a methodology had been defined that would assist future investigation of building types, and that we had also identified areas for further study, both in atria as well as window design.

Credits

Client for the study:
Energy Technology Support Unit

DSC/1 Light industrial building
Architect: Michaelis Francis Le Roth
Pseudo-client: Milton Keynes Development Corporation

DSC/2 Sports hall
Architect: Nicholas Grimshaw & Partners
Pseudo-client: Sports Council of Great Britain

DSC/3 Nurses' hostel
Architect: Robert Hurd & Partners
Pseudo-client: Scottish Health Authority Common Services Agency: Building Division

DSC/4 Secondary school (retrofit)
Architect: Essex County Council Architects Department
Pseudo-client: Hampshire County Education Department

DSC/5 Medium-rise office
Architect: Salmon Speed Associates
Pseudo-client: Hillier Parker May & Rowden

DSC/6 Hotel bedroom block
Architect: Dyer Associates
Pseudo-client: Trusthouse Forte

DSC/7 DIY superstore
Architect: Glazzard Architects Co-operative
Pseudo-client: Sainsburys Homebase Ltd.

DSC/8 Low-rise office
Architect: Building Design Partnership
Pseudo-client: Jones Lang Wootton

Photos:
Harry Sowden

JET

Tom Molyneaux
Chris Bell

Introduction

JET (Joint European Torus) is an experiment in a programme which has the aim of making available for Europe a new source of energy: that released by the fusion of the nuclei of elements with light atomic weights — the energy source of the Sun.

JET is the largest single project of the co-ordinated nuclear fusion research programme of the European Atomic Community (Euratom). The project was established at Abingdon, Oxfordshire, in June 1978 for a period of 12 years and the machine was constructed and in operation by June 1983. Its current annual budget of approximately £75M is borne mainly by Euratom (80%) and the remainder by the 14 participating countries. The project has recently been extended until 1992.

Nuclear fusion

Energy is released when light nuclei fuse together to form heavier ones. The most suitable reaction for energy production occurs between deuterium and tritium — two isotopes of hydrogen. Deuterium occurs naturally in water ('heavy' water) and is non-radioactive, while tritium (a radioactive isotope) is manufactured from the interaction of neutrons with lithium within the reactor. The major part (80%) of the energy released in the deuterium-tritium fusion reaction is in the form of a high energy neutron.

Until a few months ago conventional wisdom had been that there were three possible approaches to nuclear fusion:

(1) 'Magnetic confinement' in machines such as tokamaks (toroidal chambers) where fusion is attempted by generating extremely high temperature plasmas at a fairly low density;

(2) 'Inertial confinement' where very high energy laser beams are used to cause a fuel pellet to implode and so create very high densities;

(3) 'Cold' fusion where sub-atomic particles called muons, generated by a cyclotron, catalyze fusion reactions at room temperature (or more optimally at about 900°C).

Following the results announced by Professors Fleischmann and Pons earlier this year, it still might be necessary to add a fourth approach to this list: room temperature fusion taking place in the palladium electrodes of what is practically a battery filled with deuterium-rich heavy water. These results are still being examined and, if found to be genuine and applicable on a large scale, will revolutionize fusion research.

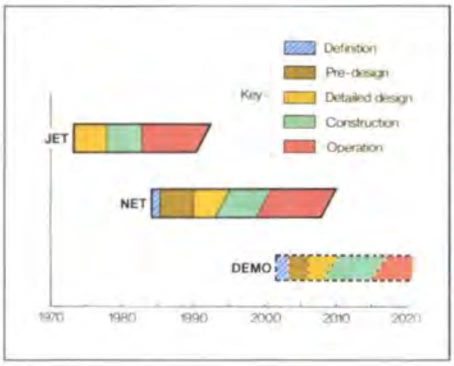
In the meantime, magnetic confinement has so far seemed to hold the most promise. JET is a tokamak, the largest and most powerful of its type in the world, and works on this principle.

The tokamak

The gaseous fuels (deuterium and tritium) must be heated to temperatures in excess of 100M°C to ensure an adequate reaction rate. At such high temperatures the atoms are ionized — becoming a plasma. As the plasma is composed of charged particles it may be confined by suitably configured magnetic fields. Using this technique the vacuum vessel can be protected from the hot plasma.

The JET tokamak is approximately 15m in diameter and 12m high. At the heart of the machine there is a toroidal vacuum vessel of major radius 2.96m with a D-shaped cross-section of 2.5m × 4.2m.

During the operation of the JET machine a small quantity of gas is introduced into the doughnut-shaped vacuum vessel (the torus).



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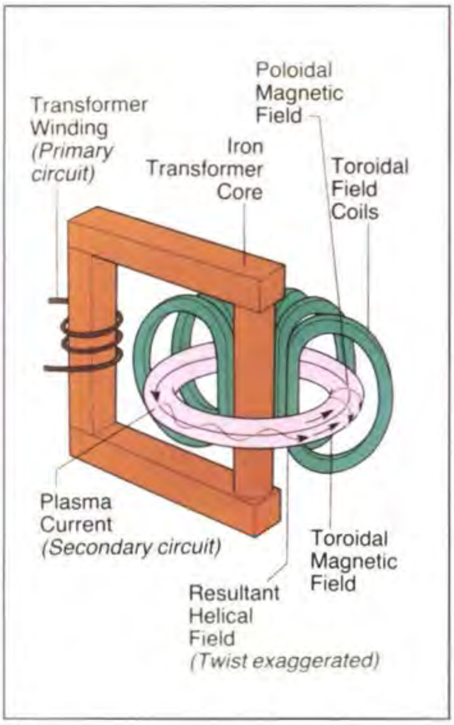

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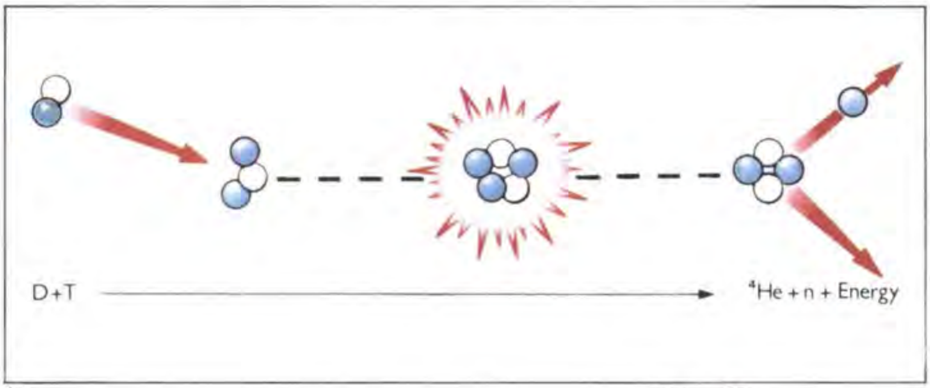

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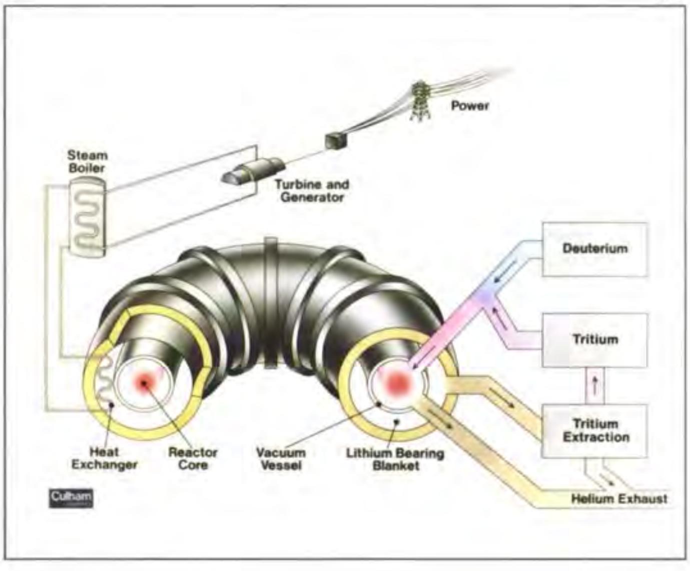
1. Fusion of deuterium and tritium
2. Route to a fusion reactor
3. Tokamak magnetic field configuration
4. Fusion reactor — schematic
5. Section of Joint European Torus

4▽



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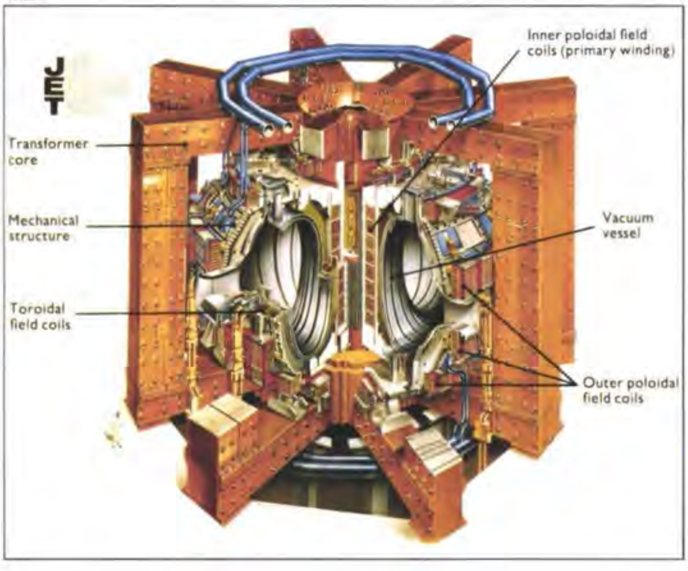

The gas is heated to form a plasma by passing a large electric current through it. This plasma current has an associated magnetic field which combines with a second field (toroidal field) produced by 32 D-shaped coils equally spaced around the vacuum vessel. The combination of these two fields provides the constraint that limits contact between the hot plasma and the walls of the vacuum vessel.

A set of six hoop coils around the outside of the vessel (poloidal coils) produce a magnetic field that shapes and positions the plasma centrally in the torus.

So far, experiments have been carried out using hydrogen or deuterium plasmas and the fusion yield, measured in terms of neutrons emitted, has been low. Consequently, the machine is only very slightly radioactive and manual access is not a problem. In the final stage of the programme it is planned to operate with deuterium-tritium plasmas so that abundant fusion reactions occur. During this phase of the operation the machine will become radioactive to such an extent that all repairs will have to be carried out using remote handling systems.

Development programme

JET had originally been designed for plasma currents up to 4.8MA. However, early results had shown that even greater plasma currents were required in order to achieve conditions approaching those of a reactor. The New JET Development Plan was formulated in 1986 and was directed towards achieving enhanced performance of the machine. A new maximum plasma current of 7MA, which would result in a doubling of the magnetic and thermal loads on the machine, was believed to be achievable and Ove Arup & Partners were asked to provide technical help for the mechanical and thermal reanalysis of the coil systems and mechanical structure required to justify operation at this higher power. From September 1986 to February 1989, two Arup engineers were seconded to JET to work on this, which involved structural analysis, specification and supervision of load testing, and the development of software to analyze instrumentation data from the machine.

Data handling

A wide range of diagnostics is employed on JET to assess the plasma characteristics and the state of the machine throughout its operation. JET uses a computerized Control and Data Acquisition System (CODAS) to provide flexible operation and storage of results.

A significant part of the project has been the development of systems to check and process the database of instrumentation results. This work has resulted in a greater understanding of the structural behaviour of the machine and provided insight into the loading history of critical components. In addition to the analysis of historical data the work has also included the development of protective software. This is capable of monitoring the operation of the machine and aborting operation that would result in excessive forces.

Coil structures

The magnetic coils of JET sustain severe mechanical and thermal pulsating loads — forces of several thousand tonnes and temperature rises of 80°C in 25 seconds are typical. The coils are constructed of copper (with integral water channels for cooling) and glass-reinforced epoxy resin. The replacement of a coil would be a major task involving considerable down-time. Furthermore, in the later stages of operation (the tritium phase) such an operation would involve the adoption of remote handling techniques due to the high radiation levels.

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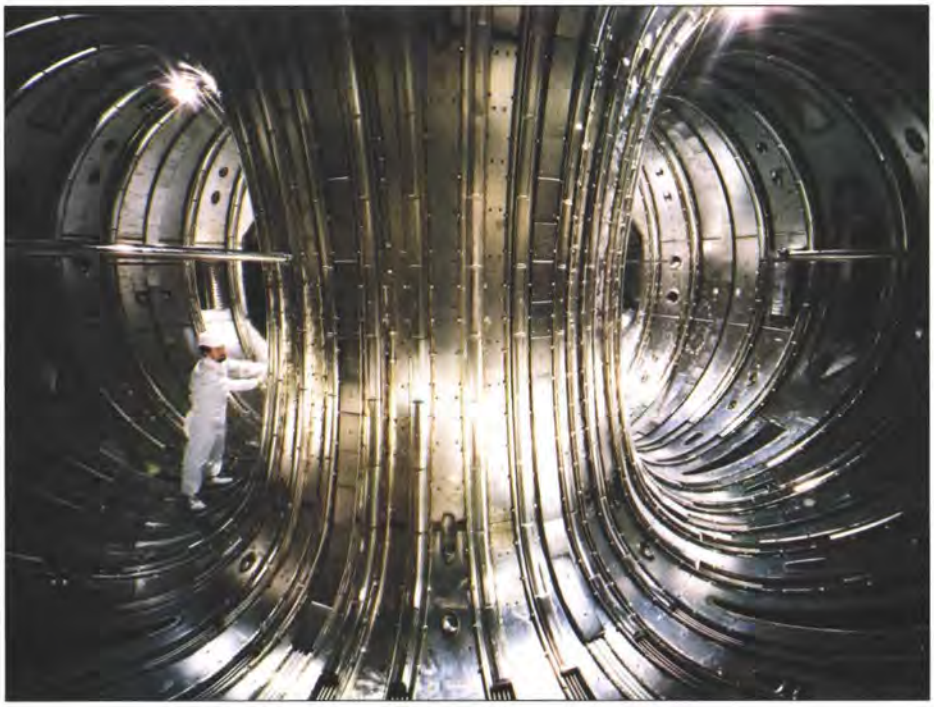
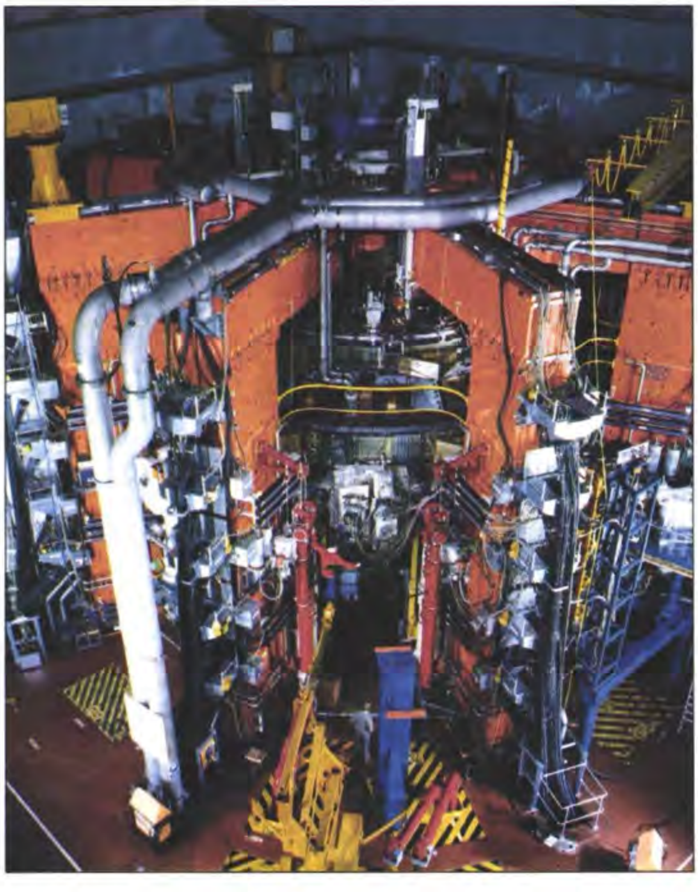
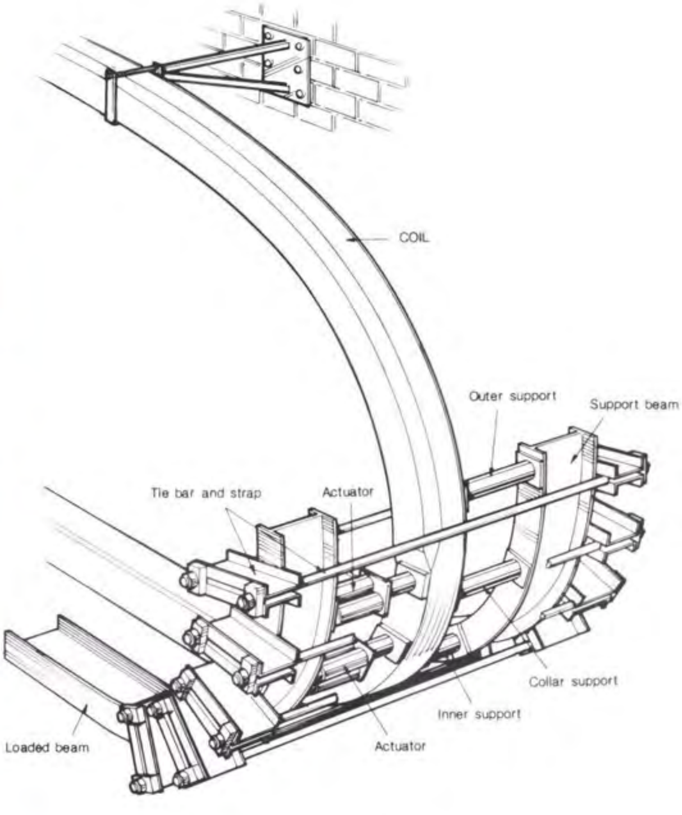
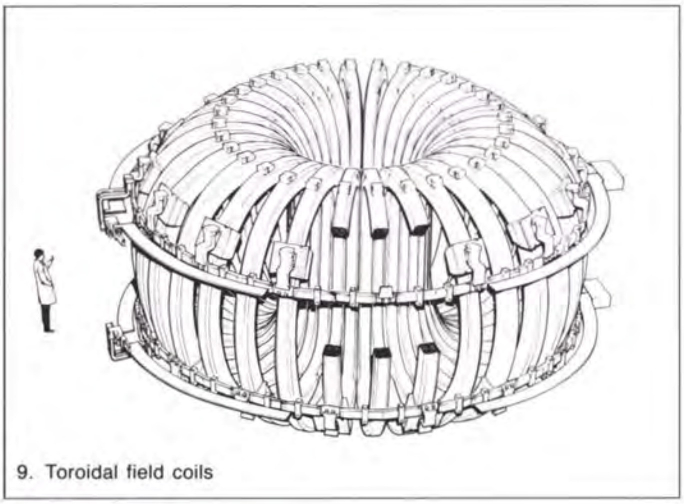
6. (below): The JET vacuum vessel
7. (bottom left): The JET machine
8. (bottom right): TF coil test rig

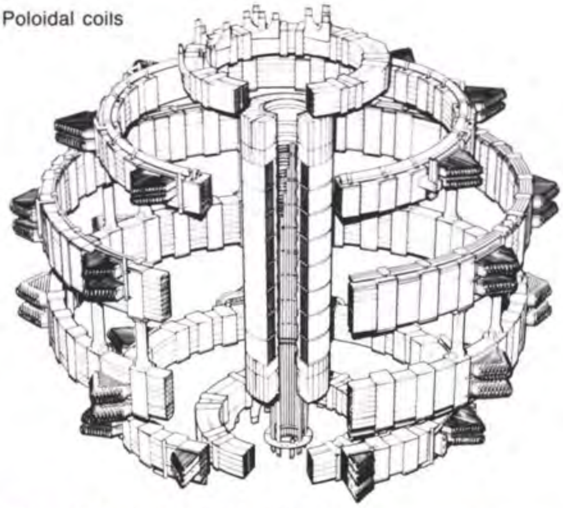




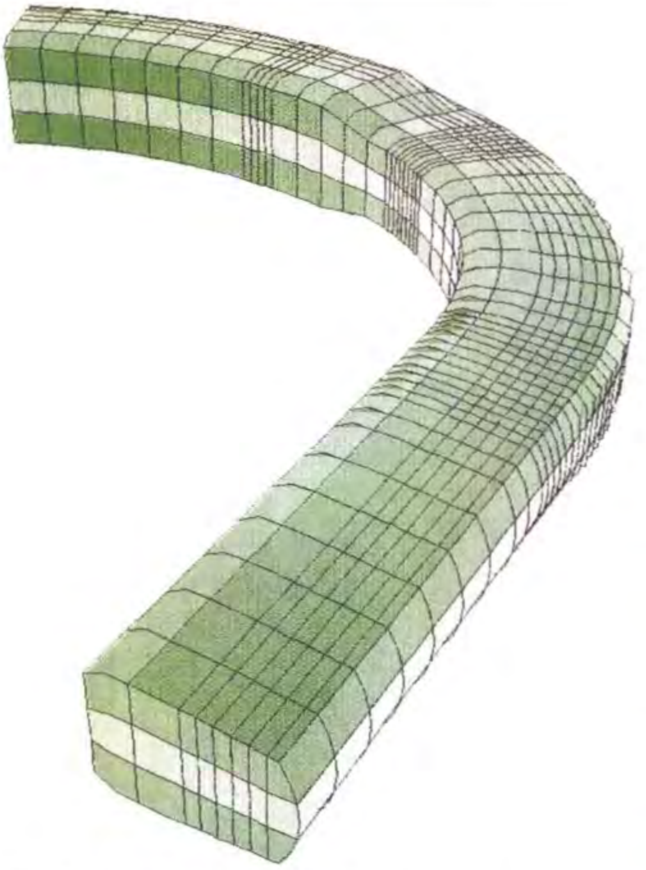




9. Toroidal field coils



10. Poloidal coils



11. Finite element model of TF coil

▽ 12. Toroidal field coil under construction

▽ 13. Lower outer poloidal field coil under construction

Toroidal field coils

The copper windings of the TF coils are loaded as a result of their own toroidal field and the poloidal field. The response to the toroidal field is to produce in-plane forces — a net force acting towards the centre of the machine and a tensile hoop force in the windings. The D-shape of the coil is designed to minimize the bending moments around the coil resulting from the combination of these forces. (Consider the D-shaped cross-section of a water droplet on a horizontal flat surface.) The reaction of the coil to the poloidal field takes the form of out-of-plane forces resulting in an overall torque on the machine.

To resist the out-of-plane loading (typically 50t/m span), the coil is supported continuously along its straight (inner) side and at discrete points elsewhere. The net in-plane force (typically 2000t) pushes the coil into a cylindrical bearing surface (flute) along the straight side — thus providing the lateral support for the normal loads at this position. The coil is free to pivot in the flute.

Analytical work highlighted critically stressed regions of the coils and a load test on the prototype coil was conducted to confirm overall safety factors. The prototype coil had been fabricated prior to the manufacture of the in-service coils in order to demonstrate the proposed assembly techniques. During the course of the test over 145 000 load cycles were applied to the coil with a maximum load of over 230t — the coil was undamaged by the test.

Poloidal field coils

There are two types of poloidal coils — a stack of 10 inner coils situated at the very centre of the machine and six outer coils around the outside of the vacuum vessel. The inner coils form the primary winding of the transformer that generates the plasma current. The outer coils are employed to shape and position the plasma.

As with the TF coils the two critical loading components are electromagnetic and thermal. At full projected current the compressive force in the middle of the central coil stack is about 9000t and the temperature rise about 60°C. The analysis showed that the coil cooling system would have to be modified so that the coil was cooled with hot water in order to limit thermal gradient stresses. It has also provided enough data to generate diagrams showing the safe regions defined by coil current, plasma current, TF coil current and temperature, within which JET may be operated. These show that the target plasma current of 7MA is, just, possible.

The future for fusion in Europe

JET achieved a record plasma current of 7MA on 23 August 1988. In October 1988 it was announced that JET had achieved separately the plasma parameters of temperature, density and confinement time required in a fusion reactor (but not all at the same time). The success of JET has focussed attention on the next step — the Next European Torus (NET). A NET Design Team was established at Garching, Federal Republic of Germany in 1983, to which there are currently three engineers seconded from Ove Arup and Partners.

Credits

Client:
JET Euratom
Mechanical engineering consultant:
Ove Arup & Partners
Illustrations:
Copyright JET Joint Undertaking

Hasbro Inc., Stockley Park

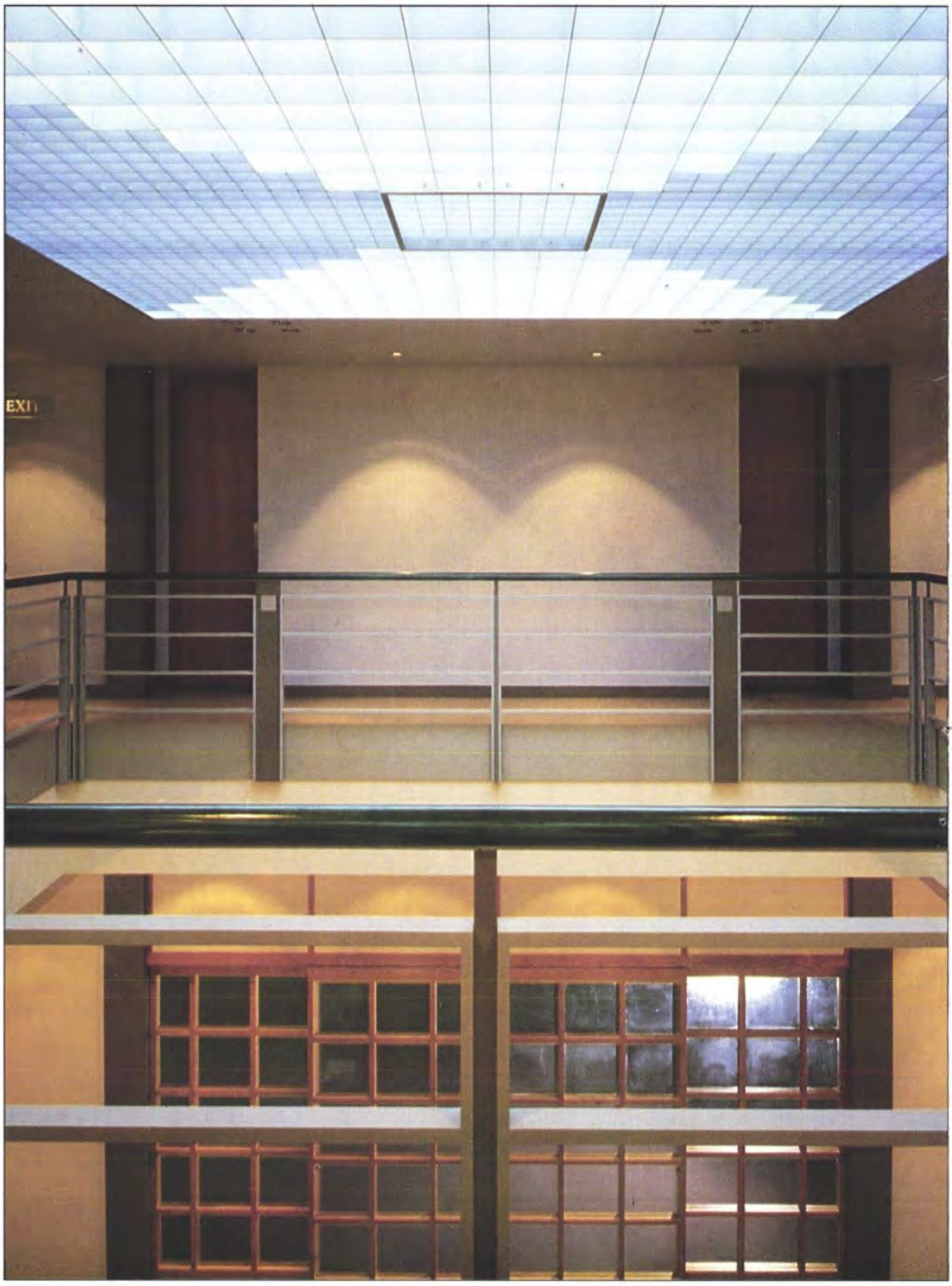
Arup Associates
Group 3

Since the preparation of the Master Plan for Stockley Park in 1984 Arup Associates have designed 12 new buildings on the site. One of the most recently completed has been designed for the American toymakers, Hasbro Inc.

Located at 2 Roundwood Avenue to the east of the Arena and clearly visible from the main entrance to the site, it consists of two linked pavilions each two storeys in height, planned around linked internal atria. As well as providing a range of office workspaces, there are showrooms and a specially designed presentation suite. An octagonal conservatory houses a coffee lounge with a mezzanine dining area above.

Arup Associates worked together with Sussman Prejza of Santa Monica, Los Angeles, on the design of the interiors, and with the art consultant Nancy Rosen on the choice of artists' works for the building. These include pieces by Michael Craig-Martin, Julian Opie, Patrick Caulfield, Barry Flanagan and several others.

Following the submission of outline proposals in July 1987, construction started on site on 3 August 1987 and the finished building was fitted out for occupation in November 1988.

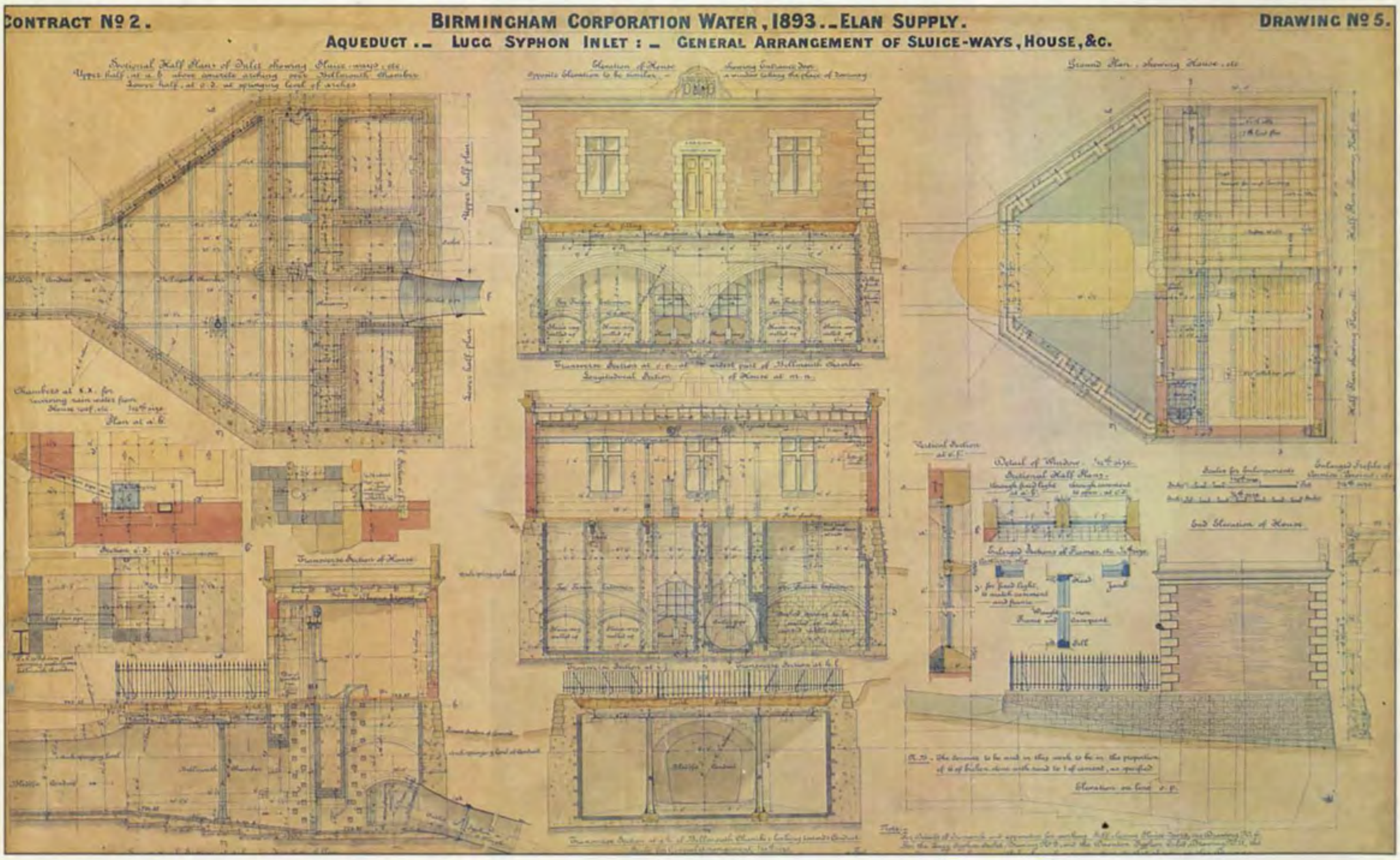


Credits

Arup Associates
Architects + Engineers + Quantity Surveyors

Consultants

Interior designers:
Arup Associates/Sussman Prejza, L.A.
Space planning:
D.E.G.W.
Restaurant facility and storage proposals:
Jolyon Drury Consultancy
Lighting:
Derek Philips Associates
Art consultant:
Nancy Rosen
Photos:
Peter Cook



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