# THE ARUP JOURNAL

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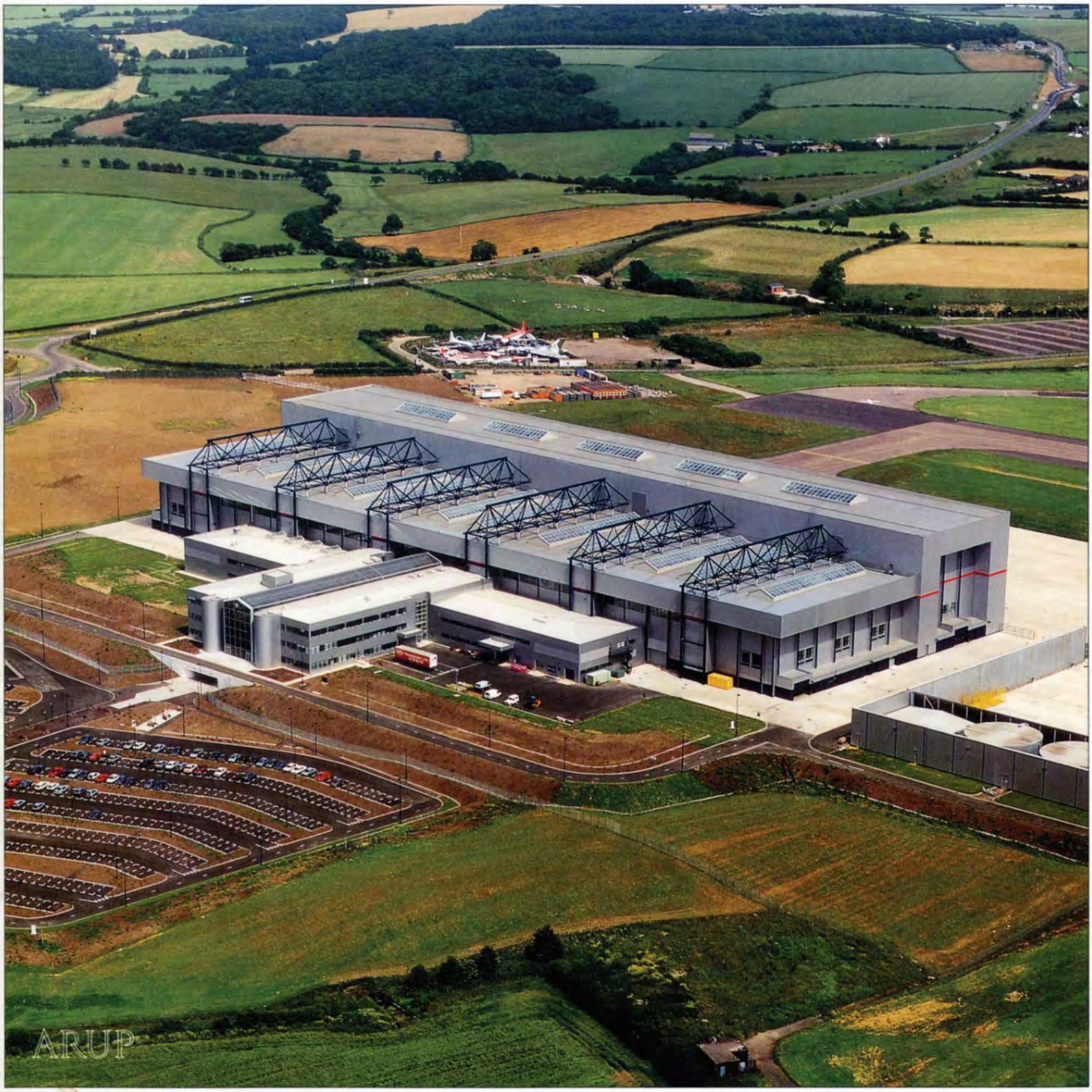

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**Front cover:**
Project Dragonfly. (Photo: Ken Newman)

**Back cover:**
Holborn Bars. (Photo: Peter Mackinven)

# 'Future Assurance': The redevelopment of Holborn Bars

**Architect: EPR Architects Ltd.**

David Atling   Ken Coffin   Ian McVitty
Patrick Morreau   Roy Wheeler

## Introduction

Holborn Bars is both the name and the location of the newly renovated and partly redeveloped offices in London of the Prudential Corporation. It has been their home since 1875, when the directors decided to move west from Ludgate Hill to Holborn, where land was available on what had once been a Roman road from London, and which had again become a major thoroughfare with the opening of Holborn Viaduct. Here, between 1876 and 1901, the Prudential constructed, to designs by Alfred Waterhouse and in stages dictated by site acquisition, the brick and terracotta buildings which became a London landmark (Fig. 1).

1. Holborn elevation c. 1905.

During the 1980s, the Prudential again recognized the need to change their premises, this time for efficiency rather than expansion. The piecemeal growth of the 19th century and some subsequent redevelopment (Fig. 3) had created problems which they now sought to address. Chief among these were the variety of floor levels and tortuous communications between the various buildings; the inefficiency of the floor plans; standards of heating, cooling and ventilation inappropriate for the 20th (let alone the 21st) century; and the total absence of provision for the information technology essential to operate such a diversified financial services organization.

## Gaining the objective

The Prudential's goal was straightforward: a modern office building of at least the same floor area on the same site — a simple enough objective, but not easily achieved when the outmoded buildings are listed Grade II* and designed by one of the great names of Victorian architecture. Total demolition and redevelopment was out of the question, nor did the Prudential consider it: the buildings had become a symbol of the company, to be conserved and modernized as far as possible. Nonetheless it was evident that, whatever the scope of the works proposed, gaining the necessary listed building and planning consents would require careful preparation.

As a first step, the Prudential commissioned Dr Colin Cunningham, a recognized authority on Waterhouse and his work, to prepare a brief history of the site and an appraisal of the architectural quality of the various buildings on it[1]. Dr Cunningham's report makes fascinating reading, but space does not permit more than a summary of his main conclusions: that previous piecemeal growth allowed the possibility of sectional redevelopment, but not at the expense of Waterhouse's overall concept of a façade to Holborn backed by a sequence of courtyards. This, and the detailed recommendations of the report, formed the basis of the planning concept adopted by the Prudential Architects Department as they, with Ove Arup & Partners as structural and building services engineers, DEGW as office planning consultants, and Gardiner & Theobald as quantity surveyors, developed a scheme for discussion with English Heritage, the Victorian Society, other amenity groups, and the planning officers of the City of London and Camden Borough, in whose two jurisdictions the site lies.

2. Site map.


The fundamentals of the scheme were to retain those buildings identified by Cunningham as essential to Waterhouse's concept; and to demolish the 1930s building along Brooke Street, the relatively inferior 19th century buildings at the rear of the complex (keeping only one of the oldest — the 'Jewel' — a small building at the north-west corner), and two 1920s buildings on the far side of Greville Street, which would be closed to extend the site northwards to Beauchamp Street (Fig. 2). In architectural terms, the two key issues were how to join new to old, and how to achieve an exterior which neither clashed with Waterhouse nor imitated him.

The first was resolved by retaining the original lightwells with their white glazed brick walls, adding glazed roofs to convert them to atria, and so articulating the junctions between retained buildings and the new development. The atria thus became major architectural spaces, detailed and finished with granite and marble on the columns and, in the circular main atrium, a sweeping spiral staircase with a 5½ tonne granite sphere (the 'Kugel'), rotating on a film of water, to act as a focal point. For the external elevations, the architects adopted a vocabulary of proportion, detail and material that echoed Waterhouse: granite panels mounted on frames integral with windows, cornice, and other details. Two colours were used, the lighter above, and the elevations were stepped back to make the building appear less imposing (Fig. 4).

This scheme, which left the main frontages to Holborn and Leather Lane restored but unchanged, was the basis of extensive discussions with English Heritage and others, and was granted planning permission in December 1988. At this stage, the Prudential retained EPR Architects to carry the project forward to detailed design and see it through to completion.

3. The site from the south-west, before redevelopment.

4. North-west corner new buildings, showing stepping of façade and colours.

5. The completed redevelopment, from the north-west..

Thus the Holborn Bars development comprised three distinct areas (Figs. 5, 6):

- the 9000m$^2$ Holborn frontage — described by Cunningham as the 'Flagship' of the Prudential — to be renovated and heated and air-conditioned to modern standards without, as far as possible, alteration to its listed interiors
- the remaining Waterhouse buildings (24 000m$^2$) to be stripped internally and refurbished as 'shell and core'
- 36 500m$^2$ of new buildings to be constructed to a high specification and completed as 'shell and core'.

Although it was anticipated that some buildings would be occupied by the Prudential, separate lettings in the future were a possibility and so, for that purpose, the new scheme was designed so that each block could if necessary function independently, with its own (or a shared) entrance and core.

Thus the complexities of circulation were resolved.

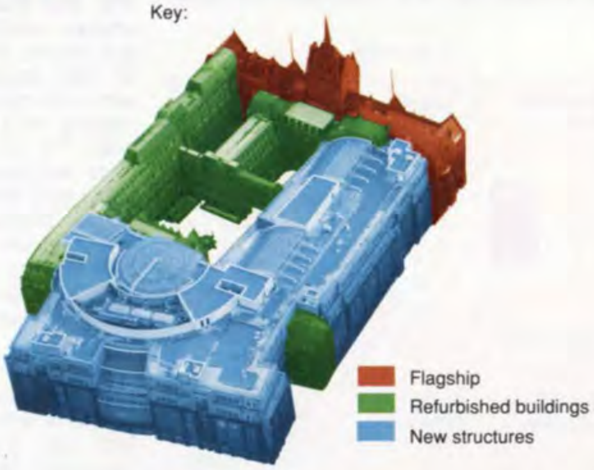
**The engineering issues**

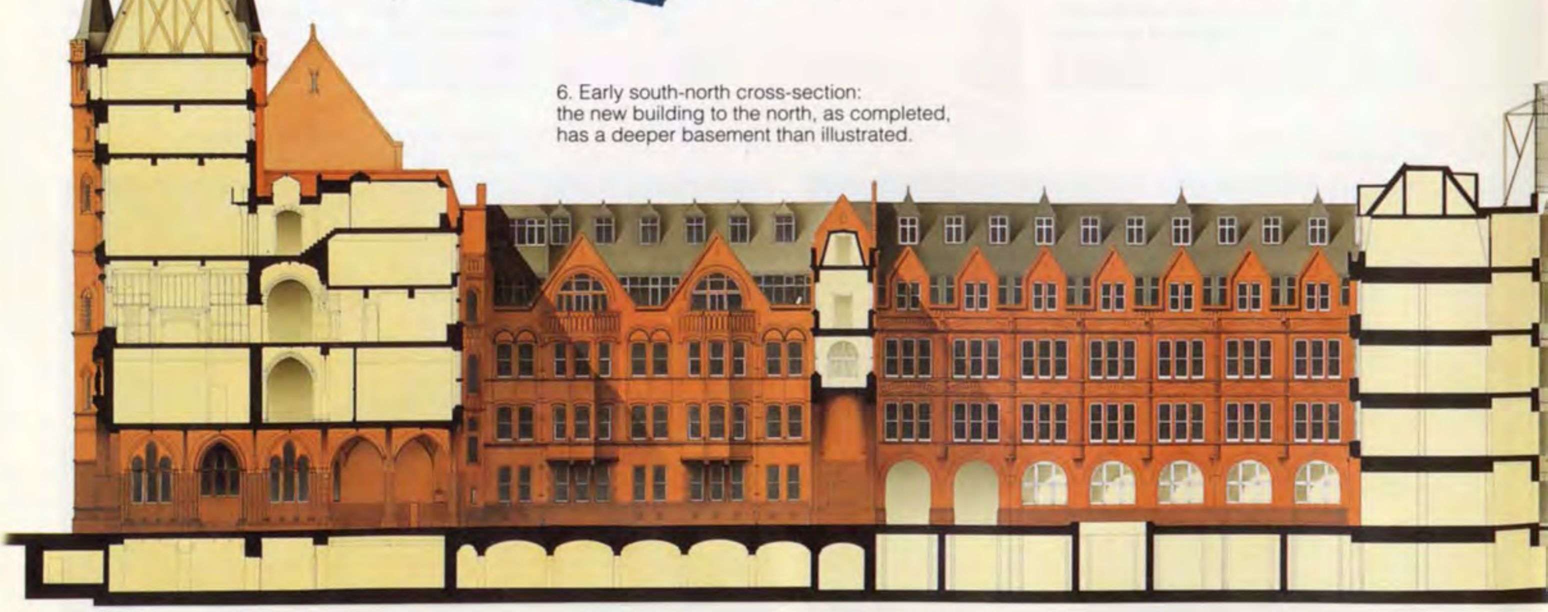
For the structural engineer the principal issues particular to Holborn Bars were the condition and load-carrying capacity of the existing buildings, the effects on them of the new construction, and the alterations needed to install the new services.

The strategy for building services was crucial. Discussion with English Heritage and the planners revealed that space for rooftop plant would be severely restricted, so to avoid using office quality accommodation for services installations, basement locations were considered. The subdivision of the development into three possibly differing tenancies suggested that each block be provided with its own plant, though considerations of outlay dictated that centralized chiller, boiler, and water storage systems be provided in a basement plantroom below the new building at the northern end of the site.

A 1.5m deep basement level building services trench provides the distribution route between the central plantroom and the numerous services risers located throughout the complex.

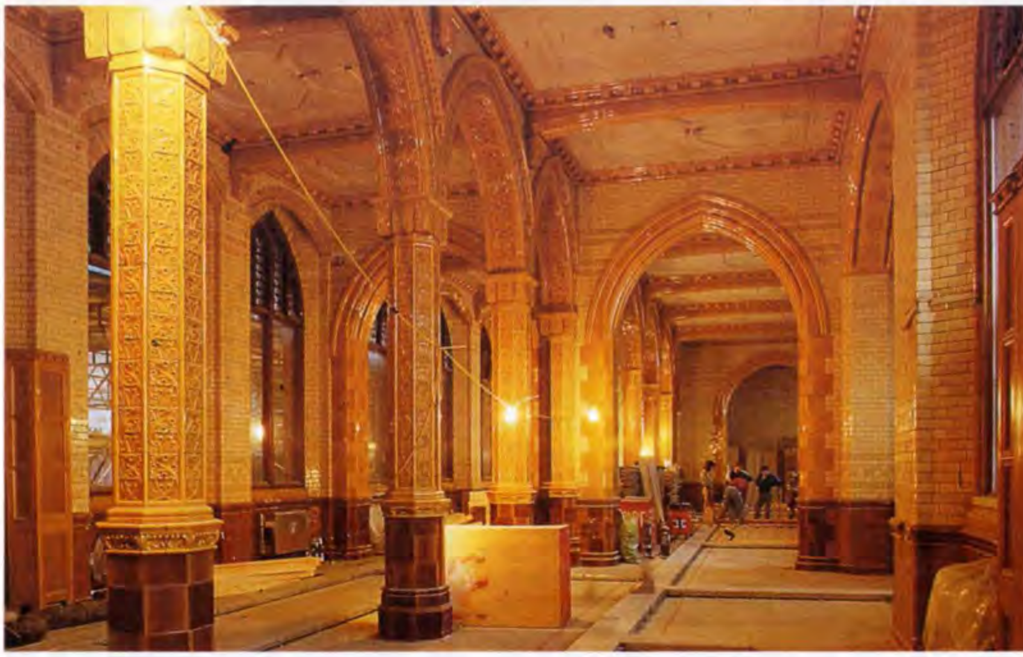
With the centralized plant strategy established, the challenge still remained of accommodating the distributed plant within the restricted space available in the refurbished buildings and the Flagship.



6. Early south-north cross-section: the new building to the north, as completed, has a deeper basement than illustrated.

7. Chiller room.



8. Interior of the Flagship, showing installation of services trunking at floor level.

## Building services

*General*

The central plantroom houses 6MW of chilled water plant (Fig. 7), 5.1MW of boiler plant, the central water storage system, an emergency generator enclosure (with the landlord's 500kVA essential services generator and space for up to 5.5MVA of tenant's generators), basement air-handling plant, and a 3.6MVA substation to serve the plant.

Adjacent to the central plantroom are intake rooms for other utilities:

- gas supply for tenants' catering facilities
- 11kV electrical supply
- BT and Mercury.

Electricity is distributed from the intake room at 11kV to substations in each of the three 'tenancy' blocks and central plantroom area.

A central addressable fire alarm system is provided to protect the development, with landlord's areas fully fitted out and connection points for tenants' future use located in the numerous building services risers.

It was anticipated that the retained existing drains and sewers would be in poor condition, and a CCTV survey confirmed that extensive remedial work was required.

Connection into the existing sewer running under High Holborn was particularly difficult, since the new outfall from the complex required extensive tunnelling; this revealed unrecorded statutory services such as a walk-through BT cableway.

In all, 28 lifts were installed throughout the complex.

For the new buildings, on-floor VAV (variable air volume) air handling units (AHUs) were accommodated in areas adjacent to cores, provided with connection points to allow future installation of on-floor distribution ductwork by tenants. In the refurbished areas the location of such plant was not possible, due to the existing storey heights and the limited areas. The solution adopted here was to use central AHUs located in pitched roof voids and lower ground floor plantrooms: both locations required major structural alterations.

*The Flagship*

Early in the design stage it became clear that the Flagship would be reoccupied by Prudential staff. The sensitive nature of the interiors dictated that it should be fully fitted out by a specialist team with experience of this type of work.

High 'sculpted' ceilings and predominantly tiled and wood panelled interiors offered little accommodation for vertical and horizontal servicing. New risers were created in the existing structure, both behind original finishes and within new enclosures finished to match the individual decor of each office. Horizontal servicing required the recreation of sculpted ceilings below originals, giving void space for ductwork and wireways. The ornate Boardroom ceiling was recreated incorporating supply and return air diffuser plates above decorative brass grilles. (This required a computational fluid dynamics (CFD) study to predict the room air flow pattern, the theory of which has since been confirmed by smoke test.)

A new false floor of the shallowest achievable depth, to minimize impact on original skirting and marble fire place surrounds, has been created, incorporating flush floor trunking with floor outlet boxes for power, telecommunications and network wiring (Fig. 8).

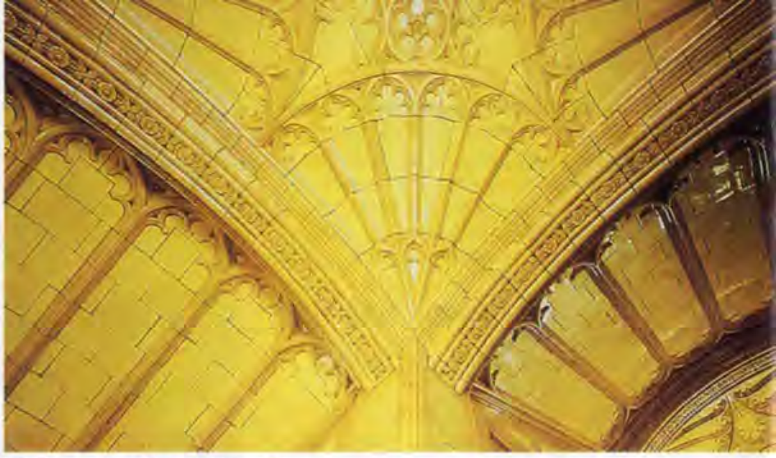
To allow the extensive installation, all wood panelling and doors were identified and removed for safe storage. A close temperature and humidity control scheme was designed and installed for this storage area to prevent possible damage due to shrinkage.

Air-conditioning of the Flagship is generally by cill-level four-pipe fan coil units (FCUs), installed within retained or new wood panelled casings. The FCUs are served by remote fresh air plant with humidity control to protect the listed finishes. The retained or new FCU casings also house chilled water, heating water and condensate pipework, power supply cabling, four-port control valves and an individual ddc controller linked to the building management system (BMS). Areas away from the listed interior offices, where accessible ceilings are installed, are provided with ceiling-mounted fan coil units or, where possible, VAV units fed from a central VAV AHU.

The Flagship lighting has involved close liaison with heritage groups to recreate the mixture of Victorian, Edwardian and 1930s luminaires, using high efficiency lamps for improved lighting levels and running costs. A variety of fittings have been used to suit individual office decor; in some cases these incorporated individual three-hour emergency lighting modules.

The nature of this building eliminated sprinkler protection, but means of escape, compartmentation, fire detection, and fire fighting facilities have been improved. Fire detection is via a fully addressable system incorporating smoke detection, breakglass units, sounders and plant overrides, with new hose-reels and dry rising mains installed for fire fighting purposes. Hose-reel outlets have been carefully integrated into the existing decor and sounders have been hidden from view in the most sensitive areas.

9. The central courtyard.



10. Faience roof in the Flagship.

*Refurbished buildings*
The refurbished buildings surrounding the central courtyard (Fig. 9) and fronting Leather Lane have listed façades and minor areas of listed interior. Generally, the interiors have been completely refurbished to create a modern office environment, and subsequently the refurbished buildings have been fitted out to developers' finish standard, providing fully serviced office space ready for tenants to partition as required. Offices are air-conditioned from fan-assisted VAV terminal units located in ceiling voids, complete with low temperature hot water re-heat coils, individual control via a ddc controller linked to the BMS, and supply and return air from central VAV AHUs.

Lighting is by modular fluorescent air-handling luminaires and perimeter downlighters, arranged to allow partitioning flexibility, while maintaining lighting levels. The fully accessible metal tile ceiling also incorporates full sprinkler protection using pop-down sprinkler heads and smoke detection, linked to the east court building addressable fire alarm system via riser link boxes.

The fit-out also provides a fully accessible false floor, incorporating an underfloor plug-in bus-bar system and wireways for tenants' telecommunications and data wiring. The combination of false floor and ceiling, coupled to letting agents' floor to ceiling heights, all within the existing structural zone, proved a major co-ordination feat.

*New buildings*
The new buildings have been constructed to shell and core standard, with the exception of a show suite at level three fully fitted-out to indicate to potential tenants how it may look.

New cores have been constructed providing plantrooms, passenger and fire lift installations, fully fitted toilet facilities, building services and fire protection risers, with plug-in points for tenants' connections at each core, on each floor. Fully functioning on-floor VAV AHUs are provided, requiring only the tenant's system.

For normal and smoke ventilation, the four new atria have variable speed mechanical extract systems, whilst the conservatory is naturally ventilated via roof units. Inlet air at the atria bases comes from a mix of automatically operated doors and louvres. Each atrium system is activated by its own beam smoke detectors via the addressable fire alarm system.

Each core has its own sprinkler main, fire alarm link box, hose reel outlet, and dry riser, with facilities for extension to provide full fire protection services for future tenants.

*Building management system*
Holborn Bars is provided with a central management suite, where building services control and monitoring is carried out by the BMS system via local outstations within control panels and terminal direct digital control (ddc) units. The BMS provides facilities for plant monitoring and set point control as well as time event control and management functions, such as maximum demand monitoring.

The fully addressable fire alarms system provided within each of the three buildings has been linked back to the management suite via a central monitoring processor, which provides overall complex control on a block-by-block evacuate-and-alert basis. In addition, the central fire alarm system controls plant installations under fire conditions, without the need to 'hard wire' between the various systems.

**The existing structures**
The Waterhouse buildings are among the earliest examples of steel construction: loadbearing brick exterior walls with terracotta ornamentation, internal rivetted steel columns and girders built up from angles and plates, and rolled steel beams supporting, in the main, filler joist floors. An exception is the 1895 building at the north end of Leather Lane where a deep steel trough deck — Lindsay's patent decking — spans directly between masonry arches. Later construction includes two floors of reinforced concrete added during the 1920s to all the buildings behind the Holborn façade, and the southwest corner of the Holborn frontage, a 1930s steel and concrete reconstruction of the first of the buildings on the site.

All the buildings have a basement (now the lower ground floor) at approximately 3m below street level, and all are founded on strip or pad footings on the gravel directly below the basement and immediately above ground water level.

The loadcarrying capacity of typical parts of the existing structure was evaluated by calculation using information from some of the 4000 drawings in the Prudential archives, site measurements from surveys and trial pits, and laboratory testing of samples taken from various materials used in the construction. From these studies, it was apparent that the floors added during the 1920s used what reserve there had been in the original walls, columns and foundations, and that these elements would have to be strengthened if they were to carry any further additional load. In the subsequent development of the design, every effort was made to avoid this. The calculated capacity of the floors themselves varied considerably but was nowhere found to be less than 3.5kN/m$^2$, the statutory minimum.

The existing buildings were found to be sound; although there had been some cases of local damage from rainwater penetration, these were remarkably few; altogether, the condition of the fabric reflected the Prudential's high standards of maintenance. Although isolated instances of corrosion to steel lintels were found during the renovation of the exterior brick and terracotta, the works on site revealed nothing to alter the view that, properly maintained, the buildings had a long life ahead of them.

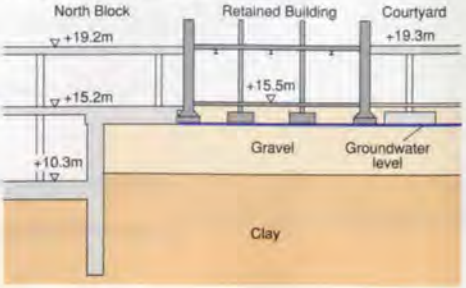
**New structures**
For speed of erection and to reduce weight on the raft foundations, the superstructure of the new buildings is a braced steel frame with columns on a 9m x 7.5m or 9m x 6m grid supporting primary and secondary beams; the floor slab is of metal decking topped with a 130mm lightweight concrete deck acting compositely with the beams. Allowable imposed loading is 5kN/m$^2$.

The space for services was carefully planned with deflection limits imposed to ensure an adequate ceiling void. Holes were provided through the steel beams to allow for sprinkler and drainage pipes, thus freeing the area below for ductwork and cabling only. Floors were stabilized by diagonal bracing in the core areas. In addition to analytical predictions of lateral deflection under wind loads, some allowance was also made for movement in the bolted connections. This was a significant proportion of the total — important when considering the movement joints between the new and existing buildings.

**The effects of the new**
In general, increases in load to the columns, walls and foundations of the existing buildings were avoided, usually by screeds and masonry partitions being removed to offset the additional loads from mechanical plant at roof level and other sources. Where replacement walls and finishes had to be provided, their weight was limited to that of the original structure. For the atrium roofs, however, other measures were adopted and the tubular steel trusses supporting the glazing are cantilevered from the new structure to float over the old, with provision in the roofing detail for the sizable vertical and horizontal movements that were predicted to occur under wind load.

Indeed, detailing the interface between the new and the old buildings was one of the more difficult issues faced by both the architects and the engineers. Not only were there questions of differential foundation settlements and thermal and wind movements to be addressed, but the permitted tolerances on the new construction combined with uncertainties in the position of the old to

11. Basement plantroom excavation.



12. Basement excavation at September 1990. The retained building on the left forms the south side of the main atrium. On the right is the retained 'Jewel', with secant pile walling in its foreground.

14: Main atrium: the retained wall (see Fig. 12) is on the extreme left.

create problems calling for ingenuity from contractor and consultants' site staff alike.

*Risks of damage*

The greatest threat to the relatively brittle brick and terracotta walls of the Waterhouse buildings came from new construction below ground level. Under most circumstances, the cost of preventing damage can be assessed against the cost of repair, and some acceptable level of risk arrived at. In the case of Holborn Bars, and especially where the faience and ceramic tile interiors of the Flagship were concerned (Fig. 10), English Heritage sought prior assurance that no damage would occur; this could not be given, but it was clear that exceptional measures would be necessary to reduce the level of risk to a practical minimum.

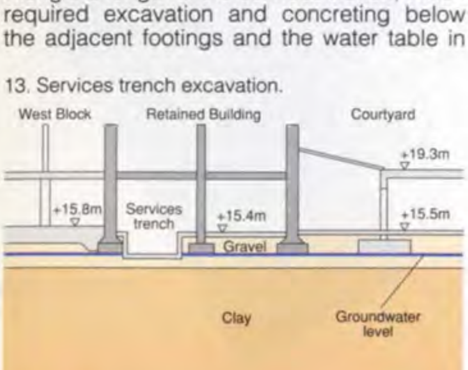
Three sources of ground movement were of particular concern: the basement excavation (Fig. 12) extending 5m below and as little as 3m away from the foundations of the existing buildings (Fig. 11); the service corridor with its building services trench between and slightly below the foundations of the western block of retained buildings (Fig. 13); and a deep lift pit abutting the finest tiled staircase in the Flagship. Fortunately, the effects of these three did not interact; each could be addressed and resolved separately.

Cost and programme considerations had led to a raft foundation under the new buildings and the basement plantroom. The basement walls were constructed with secant piling propped at two levels during excavation and supported by an earth berm at the base. The risk of damage from basement construction arose from ground settlements caused by inward movement of the toe of the retaining wall. Because the strength and stiffness of the clay soil within the excavation diminish with time (as the clay becomes 'drained'), giving rise to progressively greater wall movements and settlements at ground level, the contractor was required to complete the basement raft construction against any section of the wall within 40 days of removing the berm or, failing that, to provide a further level of propping. In the event, the time criterion was always satisfied.

*Services trench*

Along the length of the services trench, which required excavation and concreting below the adjacent footings and the water table in

13. Services trench excavation.




15: North elevation with conservatory stepped to preserve rights of light for existing residential building opposite.

the sands and gravel, the risks were threefold: that the excavation would cause the existing foundations to settle; that dewatering the excavation might draw down the groundwater and cause settlement elsewhere; and that installing sheet piling to uphold the excavation might cause damage through vibration. The solution adopted was minipiled underpinning of the adjacent foundations followed by a pressure-injected *tubes à manchette* grout curtain to provide a groundwater cut-off; the services trench was then constructed using local dewatering and conventional strutting and planking techniques. Similar methods were used to construct the deep lift pit at the Flagship.

*Monitoring*

Throughout these operations the behaviour of the Waterhouse buildings was closely monitored, using levelling points on the walls combined with constant careful examination. Although grouting caused some upward movements, these were reduced by adjusting the grouting pressure, minor cracks at mortar joints closed and no permanent damage occurred. The effects of the basement excavation were also monitored by inclinometers within the secant pile walls and by levelling points in the streets and on buildings around the site. All movements were within predicted values and no damage was reported to any of the surrounding buildings.

## The future of the building assured

The Prudential have given their buildings on this historic site a new lease of life which should take them into the next century, and maybe beyond. It has been rewarding to work for a client who cares about the building for its own sake, rather than only the investment or capital return it represents. The design team and contractor's efforts were publicly rewarded when the building received the 1993 City Heritage Award for Building Conservation in the City of London.

**Reference**

(1) CUNNINGHAM, Dr. C.J.K. A history and appreciation of the Prudential chief office buildings in Holborn Bars. Ward Taylor Associates, n.d.

**Credits**

*Client:*
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*Management contractor:*
Sir Robert McAlpine Management Contractors
*Illustrations:*
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2: Martin Hall/Kris Buglear. 3: © Handfords
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# British Airways Project Dragonfly

1. South-east elevation.

## Introduction

The new British Airways (BA) heavy maintenance facility, codenamed Project Dragonfly, is an outstanding solution to the provision and siting of a three-bay Boeing 747 hangar at Cardiff Wales Airport, overlooking the rolling countryside of the Vale of Glamorgan. BA wanted one of the most modern and efficient facilities in the world, to allow their subsidiary, British Airways Maintenance Cardiff (BAMC), establish the best and most successful business of its kind. At the start of the project in April 1990 there were approximately 1000 Boeing 747 series aircraft flying worldwide; it is projected that by 2010 this number will have doubled, swelling proportionally the demand on maintenance facilities. The project is part of BA's strategic development plan to ensure continued access to independent maintenance facilities, since they intend to increase their Boeing 747 fleet to 75 by the mid-1990s.

Servicing requirements are dictated by the Civil Aviation Authority (CAA) Approved Maintenance Schedule: generally this means that all 747s receive a heavy maintenance check after 20 000 hours of flying time or five years, whichever occurs first. Major servicing of each aircraft takes 12-28 days, during which all moving parts including engines, flaps, seats, undercarriage, cockpit controls, and internal fittings may be removed, inspected, upgraded, or replaced.

## The design team

Arups were first involved in December 1989, when they helped the Welsh Development Agency (WDA) to prepare a feasibility study for the hangar, in order to attract BA to the Principality. This early investigation established three options for a three-bay hangar: a 240m column-free space, an arrangement of three separate bays, and a combined double and single-bay layout. The latter was adopted by BA as being optimally cost-effective whilst retaining flexibility within the clear double-bay space for future changes in planning and aircraft design.

After this Arups received no further request for assistance until an invitation arrived from BA to submit a proposal for the design consultancy — which enclosed the WDA feasibility report to provide guidance on the scope of the project.

The Cardiff office won the commission against international competition and were appointed in March 1990 as design team leaders, contract administrators, architect, and landscape designer, as well as civil, structural, and building services engineers. Arups' services also included geotechnical, acoustic, fire, and wind engineering, the preparation of an environmental management report requested by BA as part of their good neighbourhood policy, the design of an information management system, and development of the specialist maintenance equipment.

The Alex Gordon Partnership and Gillespies were commissioned to assist with architecture and landscaping respectively. BA appointed the quantity surveyors Bucknall Austin plc and project planners Johnson Jackson Jeff Ltd.

The client's project management was undertaken by British Airways Property Branch, Property Construction Group, who are involved in a vast range of construction work essential to the continued success of the airline's international operations.

## The site

Located just 2km from the coast, the project covers 33ha at Cardiff Wales Airport, and encompasses the following facilities:

- 22 000m² three-bay hangar
- 6000m² hangar mezzanine floor
- aircraft undercarriage lifting platforms
- aircraft access docking
- overhead 10 tonne capacity cranes
- 10 000m² two-level workshop
- 5000m² three-level administration centre
- 35 000m² concrete apron
- aircraft ground run pen.

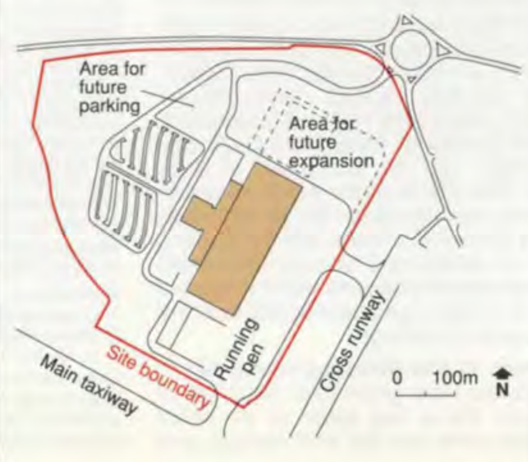
A planning study established the site layout, and also identified an area for a future fourth bay hangar to be constructed with extensions to the apron and car parking. Staff and visitor access to the building complex from the car park is via a subway below the service road. This arrangement takes advantage of the lower natural site levels beyond the building footprint to minimize ground works and to provide controlled access into the main reception area of the administration centre.

## Design influences

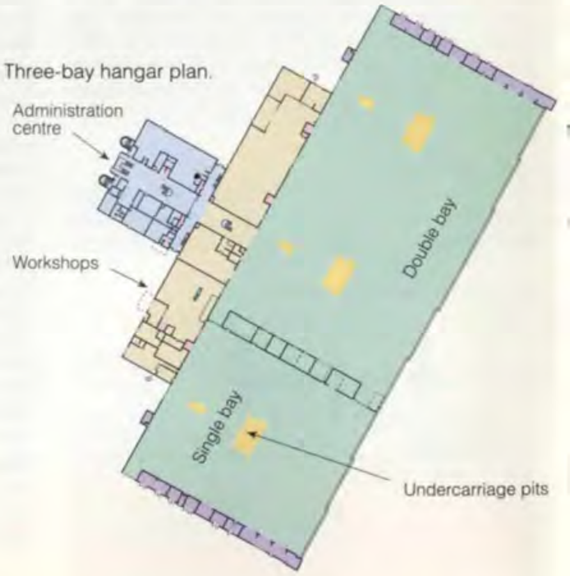
At the outset the main objectives were established with BA, the most important being to produce a facility with the lowest operational and servicing cost over a 20-year period. This meant using cost benefit analysis and life cycle costing techniques, taking account of construction and energy costs, maintenance requirements, and operational considerations using state-of-the-art technology. The internal design influences imposed by the client also had a major impact on the chosen form.

2. Site location.


3. Site plan.




4. Three-bay hangar plan.



Steven Luke


Main considerations are summarized below:

- aircraft docking position to be nose-in
- minimum internal volume to obtain maximum environmental control
- a column-free double bay, 150m wide x 90m deep
- a secure single bay, 75m wide x 90m deep
- smooth inner surfaces to minimize dust collection.

The early building studies were also influenced significantly by a number of constraints on the building form and appearance:

- large mass and scale
- location on an exposed site
- height of building relative to the surrounding area
- exposure to the elements.

In addition, the height was influenced by the 'inner transition slope' of the 'obstacle-free zone' dictated by the closeness of the runways. At the front elevation of the hangar the inner transition slope is 35m above the hangar slab and levels out at 42m over the building itself.

Exposure to salt air and discharges from a nearby power station and cement works were also important factors in the selection of the building fabric.

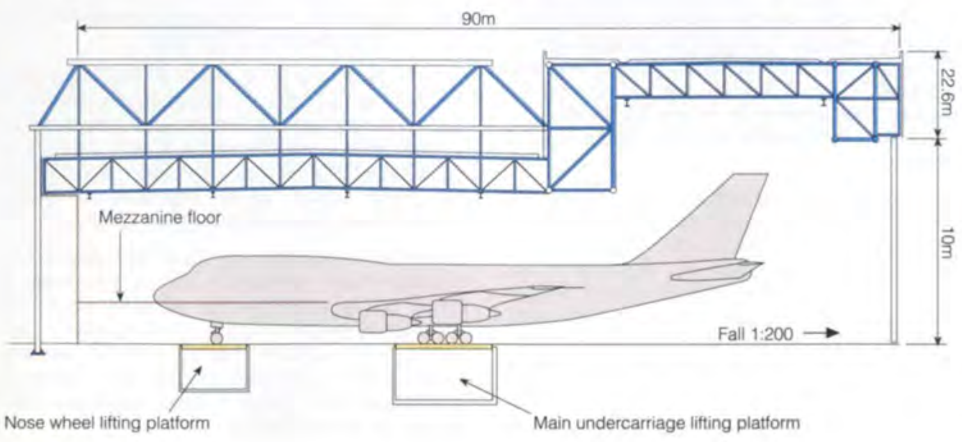
**Building form**

Much consideration was given to the elevation, to establish an interesting appearance both close to and from a distance. The profile finally chosen was a stepped roof: this suited the functions within each area of the facility, from maximum height at the front of the hangar to accommodate the tail of the aircraft to the low-rise support building at the rear. The low roof over that part of the hangar containing aircraft fuselage was lowered further to reduce the internal volume and energy requirements, by using distinctive external tubular steel triangular girders. Aesthetically, this filigree of structure combined with the external façade also reduced the apparent mass of the building from a distance by softening the stepped profile.

The study also considered the most effective support building arrangement. The chosen form separates maintenance areas from offices: they are connected by a wide circulation street with linking balconies and staircases, thus providing optimum circulation routes between the technical workshops, administrative areas, and the hangar.

6. (Above) Circulation 'street' in workshops, looking towards rear wall of hangar.

5. Hangar cross-section.




The roof over the street is fully glazed to provide a bright, naturally illuminated space.

To break up the expansive hangar façade, the wall columns, the roof structure support towers, and the roof overhangs were deliberately expressed as features. They were also used for building services distribution and maintenance access to minimize exposure within the hangar.

To test the chosen scheme, several photomontages were made, from viewing points 500m-2km from the site. A 1:1250 scale model was also produced to confirm the site planning, whilst the building form itself was studied using a 1:250 model. These aids were also used to progress the planning application.

**Envelope details**

The building fabric is insulated to at least the current Building Regulations standards and in some areas better. The cladding to the hangar walls and doors is silver/grey HP200 profiled steel single sheeting supported by cold rolled rails. Mineral wool insulation is secured to the inner face, and is protected in turn by an inner liner sheet of lightweight profiled steel sheeting. The inner skin masks all the structure and minimizes dust-collection, reducing future cleaning and maintenance. To reduce the potential for heat loss, 4.1m high doors are incorporated in the side walls for vehicle access and to avoid frequent opening of the main hangar doors.

As soon as the heating system was operational, the completed building was thermographically surveyed to confirm integrity of the insulating properties. This located weak thermal links which could not be identified by normal visual inspection.

The support building is clad with aluminium composite bi-modular panels supported by secondary sheeting rails. Office inner walls are of blockwork to control noise penetration, whilst the glazing is a thermal double-glazed system designed to allow selective installation of secondary acoustic glazing. The support building is separated from the hangar by a movement joint (concealed by detailing), needed to deal with the differential movements between the two structures generated by wind and thermal effects. The support building structure includes composite floor construction with 130mm thick power-floated floor slabs.

The hangar roof is covered by a single skin membrane, sloped at 1.5° to perimeter gutters. On the support building the roof slopes are 6° and the covering is a standing seam metal roof. Both roof areas are designed for general maintenance access and are free of external mechanical services.

The nine main hangar doors are vast — each is 22.6m high, nearly 26m wide, and weighs 45 tonnes. Arranged in sets of three, with each supported on a rail recessed into the hangar slab, they can be opened to allow a maximum of two bays to be accessed fully at the same time. Many existing BA hangars have doors fully glazed, but following a natural lighting design study, much-reduced glazing was recommended since the hangar faces south-east, and during the winter months will be subject to low sun angles which could cause glare. This study established that with 20% roof glazing and 15% glazing in the hangar doors, the lighting and internal environmental control was optimized by balancing heating and lighting costs. The distribution of glazing provides a low level vision panel plus a vertical strip aligning with the aircrafts' tail sections, giving natural lighting to the working areas. What appears to be an aesthetic consideration is in fact the result of efficient use of glazing in providing daylight distribution and amenity closely related to the building function.

## Environmental considerations

Justin Abbott

BA has adopted a 'good neighbour' policy as part of its overall corporate environmental management strategy. In support of this approach, Arups were commissioned to undertake an environmental review of the technical and management aspects of the new maintenance facility.

The review — undertaken alongside the design — concentrated on the interaction between the facility and its environment. The brief was to produce an Environmental Management Report (EMR) which should serve to:

- ensure good environmental performance during operation through the implementation of control features and operational/emergency procedures
- allow for assessment of environmental performance at a future date through the adoption of monitoring and review programmes.

The study required a thorough examination of the likely emissions from the facility. Since at the time of preparing the EMR the project was still at the design stage, it was necessary to refer to existing operations at Heathrow, where operational procedures and environmental monitoring records were examined. This information was complemented by discussions with the design team and BA staff to establish the particular characteristics of the Cardiff operations. As a result, an operational procedures flow sheet was drawn up, highlighting key emissions or waste arisings. Alongside these investigations, consultations were also held with local regulatory authorities to gain information on the ambient environment and to establish the standards that would be imposed on any emissions, in the form of either discharge consents or authorizations.

A. Aircraft *City of Norwich* in acoustic ground run enclosure.

The emissions from the facility were of five kinds: discharges to surface waters, discharges to foul sewers, emissions to atmosphere, disposal of solid wastes, and noise. For each of these the following information was presented:

- the characteristics of emission(s) and the receiving environment
- details of any discharge consents or authorizations
- recommendations for control and emergency procedures
- recommendations for monitoring and review programmes
- identification of management responsibilities.

The primary benefits expected from the review will be operational in that the implementation of appropriate control procedures should serve to minimize the risk of any adverse emissions to the environment. In addition, however, the adoption of monitoring and review programmes will enable performance to be assessed on a regular basis and will identify areas where further action may be required.

## Acoustic studies

Nigel Cogger

Acoustic studies were an important part of the Dragonfly project from the early stages:

- to ensure that environmental noise from the engine test pen would not cause disturbance to the community
- to provide a high quality working environment in the support building
- to ensure clarity and intelligibility of the public address/voice alarm (PA/VA) system, particularly in the hangar and circulation street.

An ambient noise survey in the residential communities around the Airport was initially carried out to enable environmental noise limits to be proposed. The environmental noise report and proposed criteria were fundamental to obtaining planning consent for the facility.

The design and construction of the ground run pen enclosure for test-running the aircraft engines were devised to provide maximum attenuation during engine testing. The 10m high steel-framed wall has an inner acoustic lining, with an angled precast concrete blast screen at the rear to deflect the thrusts generated during the engine run tests. The external cladding of the enclosure matches that of the hangar, the design quality being maintained as this facility is very visible from the site boundary and from the airport terminal.

The support building is sited relatively close to the pen, and the building envelope was also designed to attenuate the engine noise during testing to a sufficiently low level to avoid disturbance to the occupants and restrictions on direct and telephone speech.

This requirement is particularly important for the training rooms, which directly overlook the pen.

In addition, the detail development of the meeting rooms, training rooms, and offices had to ensure an appropriate standard of acoustic privacy. Particular attention had to be given to the video conference room linking the BA facilities, which needs a high level of noise insulation and control of reflected sound to operate suc-

### Building services

*General*

The services have been purpose-designed for the varying activities and requirements of the hangar, support workshops and administrative offices, with particular attention given to the quality of the internal environment and to energy efficiency.

Both the workshops and administration building have been designed for specific client use and are cellular in layout to suit their requirements. The offices, however, are basically open plan and the current partition layout can be modified should the users' requirements change.

The hangar floor is uncluttered, with service plantrooms along the side walls and in the dividing wall between the double and single hangar bays. A mezzanine 4.8m above the hangar slab links it with the support building and provides direct access to the aircraft and additional working space. This floor is also used for services distribution below its soffit and a substantial number of structural beams have circular web holes to allow flexibility for future installations.

*Heating, ventilation and comfort cooling*

The hangar bays are heated by a high temperature and high velocity direct gas-fired system. Air-handling units in the spine beam (which contribute 280 tonnes of load supported by the roof structure) supply air to insulated high velocity primary air ductwork systems serving strategically located induction units. By utilizing direct gas firing, and reducing duct lengths from the heating source, the system is some 95% efficient, compared to 70-80% for alternative indirect systems.

The system also destratifies the air within the hangar by forcing warm air, which naturally circulates in such a lofty space, back down to floor level, and so prevents excessive heat loss at roof level. The viability of the hangar heating system in such a high building was modelled and proved mathematically prior to construction by computational fluid dynamics (CFD) techniques.

The support building's heating system utilizes two gas-fired distributed combined heat and power (CHP) units in conjunction with top-up boilers. The CHP units provide a proportion of the building's total electrical and heating demands in an energy efficient manner and provide a measure of back-up in a power failure.

All spaces within the building are mechanically ventilated, though a good proportion of the windows are also openable.

This is generally as a result of the building's location in an airport environment and the nature of the building's functions internally. A limited amount of the office space has comfort cooling from a four-pipe fan coil unit system, with chilled water provided by water chillers using low ozone-depleting R22.

Key workshop areas are given high-efficiency displacement ventilation which provides a clean air layer within the working zone. All ventilation systems have heat recovery devices, the majority being thermal wheels which rotate between supply and exhaust airstreams and have a heat recovery efficiency of some 70-80%.

cessfully. Impact and airborne noise from the kitchen were also attenuated to avoid disturbance to the training room below — achieved by floating the kitchen's structural floor screed on a resilient layer.

Acoustic considerations also had to be observed with the design and specification of the sitewide public address and voice alarm system. While this was relatively straightforward for the support building, the long reverberation times in the hangar space (5-7 seconds at mid-frequency) posed severe difficulties with intelligibility.

Specialized 3-D electro-acoustic modelling software was used to optimize the system, the solution being to use high quality loudspeakers with a 100° coverage angle, pointing vertically downwards. Intelligibility and naturalness of voice were shown at commissioning to be better than for any other hangar PA system known to the listeners.

The emergency alarm system was treated differently, with electronic alarms being adopted to ensure clarity of operation.

## Fire safety systems

Peter Bressington

Since the hangar is an unconventional building, it was necessary for a comprehensive fire strategy to be developed, covering both active and passive protection measures. The strategy was discussed, developed and agreed with British Airways' Fire Protection Manager, the building's insurers, and the Fire and Building Control Officers throughout the development period.

The specialized fire detection and suppression systems developed for this project provide both life safety and property protection; the emphasis on a high level of fire safety with rapid extinguishment is reflected in the fact that the fire protection installation is the single most costly item of the building services.

An automatic foam deluge system protects the aircraft bays with automatically oscillating monitors (cannons) and foam sprinklers.

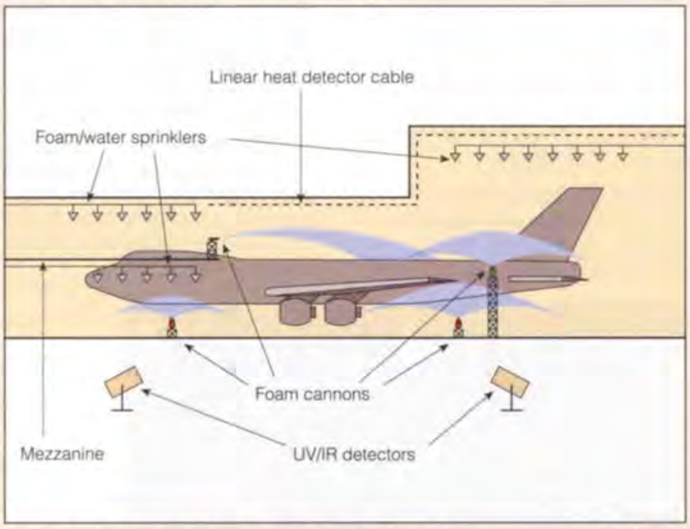
Conventional sprinklers are also included in the hangar below the underwing docking, mezzanine floor and in the hangar roof directly above the mezzanine working area.

The fire protection system incorporates storage for 4M litres of water which can be delivered at a rate of 80 000 l/min, mixed with a foaming agent, to the double bay. The pumping equipment and the water storage tanks are located at the rear of the aircraft ground run pen.

The foam sprinkler and cannon systems can be activated manually or automatically, with the detection systems responding to a 5MW design fire anywhere in the hangar. The fire detection system operates in conjunction with the PA system which sends out voice/tone alarms; a complete automatic addressable site fire detection system is provided throughout the complex. In the event of a fire the information is displayed on VDUs in three central control centres and automatic diallers give a direct alarm to the local Fire Service.

Apart from the additional, uncodified inclusion of the cannons, the design of the deluge and foam monitor system was developed from that given in the US Standard *NFPA 409*, 'Aircraft hangars', 1990 edition — the guide usually adapted for the design of hangar protection systems. Both directional throw and a minimum design discharge density over the aircraft and hangar floor are incorporated. High expansion foam generators protect the undercarriage pits. To prove the design, a full hydraulic and discharge test was arranged in the double bay as part of the planned commissioning requirements: it provided an impressive demonstration of the system's capability.

A. Section showing foam cannon coverage.




B. Full scale discharge test in the double hangar bay.

C. Foam cannon.

*Power supply*
The total power demand is supplied by three 11 000V to 415V transformers, each with a dual rating of 1.6MW. To operate the aircraft on-board electrical systems during maintenance, a 200V three-phase 400Hz power supply is provided by motor generating equipment.

*Lighting*
Within the hangar special multi-vapour lamps provide an optimum balance between lamp life, efficiency and colour rendering for particularly sensitive work. Lighting in the support building consists of high efficiency fluorescent and compact fluorescent sources with controllers such as low brightness to suit the task. Artificial lighting in the hangar and in the atrium are photocell-controlled whereas other areas have manual switches.

*Energy management*
All the building services are controlled by a computerized Building Management System (BMS), which provides energy efficient control and monitoring of plant and systems controlled by outside conditions, the calendar date, time of day, presence of people and the use of the space.

*Aircraft services*
Specialized services are provided for the aircraft whilst in the hangar. These include a 400Hz power supply system, hydraulics, fuel tank venting and high mass air by means of mobile rigs. An extensive compressed air system is provided throughout the hangar, workshops and on the docking and staging systems.

### Substructure

The soil conditions below the original ground level were found to be fairly uniform: a thin layer (about 250mm) of topsoil over completely weathered Porthkerry formation becoming moderately and slightly weathered with depth. Ground conditions were good and allowed mass concrete and lightly reinforced pad foundations to be specified, with 12m ground anchors in some of the foundations to resist uplift against lateral overturning loads.

The topsoil was stripped and stockpiled for use in the landscaping and all excavated material, amounting to some 120 000m³, was graded on site for use as structural material. The cut and fill requirements were balanced and all material was re-used within the site. The consistency of the bearing pressure in the weathered Porthkerry formation was monitored throughout by zone tests, in situ density testing, and rotary percussive probing.

The hangar and apron slab was unreinforced with undowelled joints, the preferred solution since it is both reliable and simplifies construction. It also avoids inducing high localized stresses in the concrete and potential for local crushing or cracking — the main consideration being to avoid small concrete particles getting sucked through the aircraft engines during taxiing across the apron to the hangar.

The use of superplasticizers was avoided and the slab finished with a mineral application and then power-trowelled to a uniform light grey colour with a dense surface to minimize chemical and oil absorption. The light grey mineral finish also helped to increase light reflection in covered areas below the aircraft wings and fuselage.

# Specialist aircraft maintenance structures

Steven Luke

### Roof cranes

The hangar roof structure is designed to support five Mannesmann Demag 10-tonne capacity cranes, one at high and one at low level in the single bay, one at high and two at low level in the double bay. They provide total coverage of the hangar floor and can act in tandem to lift a 20 tonne point load at any position. The high level cranes are single-span gantry, supported by two crane rails. The low level cranes are on five rails and the gantry beam incorporates mechanical hinges between each support rail to allow movement of the hangar roof. Each crane is provided with a side maintenance walkway, also usable for access to the roof fittings. This equipment contributes 250 tonnes to be supported by the roof structure.

The cranes operate by infra-red system. A radio control alternative was considered but discounted due to the interference which may occur in an airport environment.

### Undercarriage lifting platforms

The lifting platforms are provided in the floor below the nose and main undercarriage wheels. This equipment incorporates electro-mechanical screw jack devices in concrete pits up to 6m deep: installation design was completed by GEC Alsthom. The platforms can support the maximum aircraft weight of 250 tonnes, though the normal unladen weight during maintenance conditions is about 150 tonnes. Each set of platforms can operate between these weight limits at speeds from 60-600mm/minute. The platforms are used to level the aircraft before servicing commences, following which it is supported by four load-bearing trestles along the fuselage and steadies below each wing. After this operation is complete the platforms can be lowered by up to 2m to allow removal of the undercarriage wheels for retraction, testing and servicing. Each platform can also be raised a maximum of 500mm above the hangar floor slab.

The platforms are controlled from main cabinets in both side walls of the double bay and the outer wall of the single bay, as well as from smaller remote mobile consoles which can be placed adjacent to each platform. This system has been designed with a number of safety features to ensure security of movement and avoid error in operation.

### Access docking

The lifting platforms allow each aircraft to be positioned quickly and accurately to interface with the access docking structure. These structures are specific to 747s and are fundamental to the maintenance operation, providing access to the nose, wings, fuselage, and tail. To achieve a tight fit of structure and aircraft, the tail and fuselage docking can be moved laterally on rails and vertically using screw jack mechanisms. Fine adjustment for aircraft positional tolerance is provided by sliding fingers with rubber buffer edges in the nose and fuselage docking structure, whilst the tail docking is designed to provide a nominal horizontal 150mm clearance to the aircraft in the parked position.

Because of the tight fit requirement, control of roof deflections was critical to avoid damage, and the imposed load mid-span roof deflection in the double bay area was controlled to approximately 150mm for all imposed loading conditions.

This limited the movement of the docking on the centreline of the aircraft to 100mm and this amount of leeway, combined with the features described, provides security of operation in all conditions.

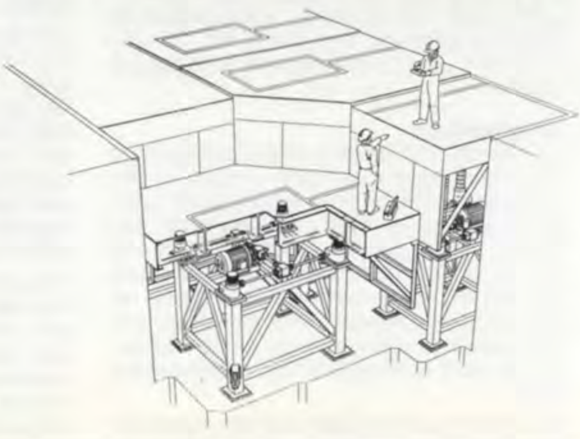
The tail docking staging is suspended from the door and spine girders. The fuselage docking structure is supported at one end from the spine girder and at the other by the mezzanine floor, these structures contributing 500 tonnes to the load supported by the hangar roof structure. Support for the tail docking from the hangar slab would have been a more economical solution but BA's preferred arrangement freed the hangar floor working spaces.

The underwing access docking is principally a fixed system supported by the hangar slab but contains moving platforms around the engine areas to provide flexibility for access at all levels.

Development of this package took the design team to Europe and the USA, but none of the facilities visited matched BA's requirement. In fact an existing BA double bay facility at Heathrow, although constructed over 20 years ago, is still considered to be the current flagship for aircraft maintenance, to be surpassed only by the new BAMC facility.

To prove aircraft fit and operation of the access docking, arrangements were made for a 747 to visit each bay before completion and the 'City of Cardiff' was the first to assist the trial fit procedure.

◀A.
Tail docking view from hangar floor showing platform profiling.



◀B.
Cut-away illustration of undercarriage platform.

◀ C. Aircraft *City of Cardiff* entering the hangar during construction for access docking trial fit.

▼ D. Engine bay.

▼ E. Aircraft tail docking.

8. Door girder fully erected, 1000 tonne spine girder awaiting lift, February 1992.

7. 600 tonne door girder lift, January 1992.

10. High level steelwork erection, March 1992.

9. Spine girder lift, February 1992.

12. (Right) *City of Cardiff* entering hangar.

**The hangar superstructure**

From the outset, the supply and erection of the hangar steelwork was identified as a critical element, with simplicity of erection a priority. Consequently, the frame concept was developed to allow each primary element to be self-supporting. Full space structures would have provided a lighter structural solution but minimum weight in this instance did not achieve minimum cost or programme.

The hangar's main members are two continuous space truss girders. The one over the main doors is 9m deep x 5m wide, whilst the spine girder at the step between the high and low level roof areas is 14.5m deep and 8m wide. They weigh 600 tonnes and 1000 tonnes respectively and are 232.5m long with spans of 153.75m and 78.75m. The total weight of structural steelwork in the hangar is 4000 tonnes plus another 2000 tonnes on the remainder of the project. The main member tube diameters are up to 762mm with wall thicknesses between 12mm and 32mm. At the main joint locations some tubes are strengthened using thicker-walled sections between 25mm and 50mm.

The roof girders were fabricated on site at ground level with built in pre-camber. The erection procedure provided a notable construction event since both were lifted into position from two points approximately 200m apart using hydraulically operated lifting towers. Each lifting operation required approximately eight hours to complete, with the girders being raised in 300mm incremental strokes to a height of 32m at their top; sliding the girders onto the main supports took a further two hours. It is believed that these structural roof members are the longest to be lifted by this method in Europe.

The infill high level roof plate between girders incorporates single-span trusses with horizontal wind bracing. The low roof is a 60m x 30m two way-spanning plate structure, and was selected to cope with the high point loading from the crane gantries. This arrangement was achieved by introducing support from the triangular girders to break the roof into small zones, and reduced the depth and weight of the structure. This concept achieved the objective of minimizing the building volume and was a prime consideration during the development of the hangar form.

There are no thermal expansion joints in the hangar roof structure and the detailing of the fabric and wall structure was developed to accommodate overall movements of 130mm expansion and 90mm contraction longitudinally. The largest positive temperature difference in the exposed triangular girders generated 10mm differential expansion and 25mm contraction. These movements were taken into account to establish the secondary effects on the support structure.

Lateral stability is provided by the high level roof plate interacting with the girder support towers, which are linked with cross-bracing to resist wind normal to the hangar doors. The wind loading on the gable walls is resisted by the central support towers and braced steelwork frames, working as vertical cantilevers in the central wall between the single and double bays. To confirm the behaviour of the principal hangar roof structure a three-dimensional spaceframe analysis was undertaken using Arups' OASYS GSA program.

11. North-west elevation.

## Information Management System

Priscilla Tang

The operation of the maintenance facilities in the hangar demands an efficient, reliable and flexible communications network. A structured cabling system was designed to provide an open solution using copper and fibre optic technologies, with centralized control and flexibility points (patch panels) provided at strategic locations throughout the complex. Voice and data services are distributed from the systems room within the administration building to offices, workshops, and hangar bays by means of patching at the flexibility points. Workstations in the hangar bays are served by additional fibre optic cables to satisfy the distance limitations specified by international network standards.

A. Fibre (left), voice (above centre) and data (below centre) terminations in hangar bay, with heavy duty power socket on the right.

B. Rear of cabinet for structured cabling termination patch panel.

BA's data networking equipment and voice system (PABX), located in the systems room, control the operations within the complex and provide connections to the BA-wide area network. The requirement for electrical/mechanical services and the layout of the systems room were co-ordinated in order to achieve effective use of space and to allow for future expansion.

A combination of the complex maintenance machinery within the hangar and the proximity to Cardiff Airport radar equipment makes the hangar a potentially hostile environment to the communications and computing networks. Frequency spectrum analyses were undertaken to assess the impact of electro-magnetic interference on the network during the design phase.


### Conclusion

Work commenced on site in early May 1991 and was substantially completed in April 1993 Following a short period for client fit-out, the first aircraft arrived for a maintenance check on 1 June 1993, 38 months after commencement of the facility, as planned at the beginning of the project. HRH The Prince of Wales carried out the official opening on Friday 30 July 1993.

An important aspect of the contract was that it required a defect-free handover to the client. Equally important, for a successful completion and to allow client training prior to commencement of the maintenance activities, was the requirement to deliver completed operation and maintenance manuals one month prior to handover. Throughout the works safety was given high priority and at peak there were 600 people working on the site, with numerous items of plant including 30 mobile access platforms and 10 cranes.

Project Dragonfly incorporated many interesting and challenging problems. As a result it required considerable ingenuity, research and development; enterprise and management skills from all parties have contributed to its success. The speed at which this complex project proceeded is a tribute to the whole team and the result can only be considered a credit to their hard work and enthusiasm.

**Credits**

*Client:*
British Airways plc
*Client project managers:*
British Airways Property Branch,
Property Construction Group
*Design team leaders, contract administrators, engineers, and architect:*
Ove Arup & Partners, Cardiff office

Gabe Treharne, Dick Hensby, Steven Luke

Alf Perry, Howard Corp, Simon Pickard, Peter Richardson (hangar structure), Justine Garbutt (structures), Adrian Baker (access docking), Richard Thomas, Kambis Ayoubkhani (civil works). Robin O'Brien (environmental management), David Fullbrook, Andrew Boughton, Bryan Williams, Franc Coles (building and ground support services), Gerald Pickin, Terry Burns, Ian Jones, Rob Gordon, Colin Williams, Mike O'Grady, Stephen Bowen, Michelle Richards, Margaret Williams (site team), Eddie King, Peter Monkley, Kevin Jones, Mike Cronly, Phil Hughes, Karen Winder, Wendy Hoare (draughtspersons).

SPECIALIST ADVISORS: Paul Craddock, Chris Murgatroyd (steelwork), Peter Bressington (fire), Nigel Cogger, Neill Woodger (acoustics), Phil King, Paul Craddock (materials), Andrew Allsop (wind engineering), Sam Shemie, Priscilla Tang (information technology), Justin Abbott (environmental).

*Architectural consultant:*
Alex Gordon Partnership
*Landscape consultant:*
Gillespies
*Quantity surveyor:*
Bucknall Austin plc
*Project planners:*
Johnson Jackson Jeff Ltd.
*Main contractor:*
Balfour Beatty Building Ltd.

*Illustrations:*
1: Courtesy Alex Gordon Partnership
2, 3: Trevor Slydel
4, 5, A(p.11): Nigel Whale
6, 7, 8, A(p.10), B(p.11), E(pp.12-13): Photos: Peter Mackinven
C(p.11): Photo: Peter Bressington
9, 12, A(p.12), D(p.13): Photos: Steven Luke
B(p.12): Courtesy GEC
10, C(pp.12-13): Photos: Ken Newman
A, B(p.15): Photos: Priscilla Tang

# Pescanova fish factory, Lüderitz, Namibia

Barrie Williams


1. Southern Africa.

2. The factory against the background of Lüderitz.


3. Model of Arups' proposal for the ultimate development.

4. Site development plan.

## The Namibian fishing industry

Namibia's natural resources, apart from the people, are primarily limited to minerals, tourism and a slowly recovering fish resource. It is estimated that in the early 1970s, fish catches were as much as five times their present level, but during the late '70s and '80s, the resource was not protected and was virtually destroyed through indiscriminate fishing by many foreign countries. Since Namibia's independence in March 1990, however, when a 200-mile fishing zone was proclaimed, foreign fleets have operated in the area only under licence. Already there are strong indications that the fish stocks are recovering and quotas for the current season have been substantially increased.

It was in anticipation of this ongoing recovery, and of the Namibian government's ability to manage the resource successfully, that the Spanish fishing group Pescanova SA decided to make an initial R140m investment. One of the world's largest fishing companies, Pescanova have operations in many countries, including Scotland, Ireland, Canada, Australia, Chile, Brazil, Namibia, Mozambique, and of course Spain.

The company's interest in Namibia is primarily in catching and exporting the white fish hake, which enjoys much popularity in Europe. Although the best fishing grounds are north of the harbour of Walvis Bay, the political uncertainty as to its ownership is still unresolved between Namibia and South Africa. Consequently, Pescanova decided to take advantage of the relatively good local fishing grounds some 400km to the south, off the town of Lüderitz which has a natural harbour.

Pescanova recognized that the Namibian government was eager to create jobs for its people and that pressure would be brought to bear on fishing companies to create work opportunities on land. The company had previously operated in the area with factory freezer-type fishing trawlers which could transfer fish to other vessels at sea for transport direct to Europe. In establishing a factory on land, their original intention was to use it only for a 'dry' process, including final quality inspection, trimming, weighing and repacking the hake into cartons and deep-freezing them ready for the supermarket shelves of Europe.

Government legislation after constructing Phase I, however, made it imperative that a percentage of wet fish production be carried out on land. This involves bringing ashore headed and gutted fish which have been stored under melting ice on the trawlers, one or two of which will operate as 'long liners'. (Imagine a fishing line up to 10km long with 10 000 hooks on it, each having to be baited by hand!)

Incidentally, the fish offal removal and screening system has been designed to cope with fish heads; environmentalists are concerned about the effects of trawlers dumping large quantities on the sea floor. Apparently hake themselves are by far the biggest consumers of hake, but they object when only heads are dished up . . .

## The site and its environs

Lüderitz is a small town of 8000 inhabitants, a fascinating, mainly German-speaking remnant of the old Colonial days, when people were lured there to search for diamonds. Apart from fighting wind-blown sand, the main occupations of the town have been lobster fishing, which only has a very short season, and servicing the local diamond industry. For the locals, general fishing does not seem to have been considered as a profitable alternative.

Lüderitz is about 780km south of Windhoek, so although there is a rail track from the hinterland, road transport involves travel over hundreds of kilometres of gravel roads. The town is also 1500-1800km from the industrial areas where many components of the facility

5. Robert Harbour, Lüderitz.

6. (below): View from east.

have been manufactured. It is surrounded by inhospitable desert and many a story is told of luckless drivers who arrive in sandstorms only to discover the paintwork on the sides of their cars has been sandblasted away.

The climate is very temperate with a maximum average annual diurnal range of only 8°C and an average rainfall of only 30mm. Not being allowed to water their small gardens, residents tend to allow them to reflect the surrounding landscape, i.e. a few rocks, much sand and maybe a hardy succulent or two (though a few years back they had three years' precipitation in one hour from an errant thunderstorm).

The most significant climatic feature, and one which has a serious effect on building design, is the wind. Although it blows mainly from one direction, i.e. the south, records show that its velocity is greater than 40km/hour for more than 40% of the year.

With its considerable sand load this had significant influence on the design of cladding, windows, doors, louvres, air filters, the carrying and offloading of fish (normally in open trays), and the orientation of the jetty.

## Background to Arups' responsibilities

Arups have been providing a principal agency and full multi-disciplinary service on industrial projects in several parts of southern Africa for many years. This project, though, has demanded exceptional communication skills because of its isolation and the necessity to involve more than one Arup office.

Although the client originally approached the architects Kerry McNamara of Windhoek, he accepted their recommendations and in March 1990 appointed Arups as principal agent, to undertake all the brief definition, site planning, engineering, management, quantity surveying and cost control.

With the architect in Windhoek, local mechanical and electrical engineers and quantity surveyors' staff were used for construction inspection and cost control. Arups' Windhoek office co-ordinated communications, handled all the local authority approvals, and provided the resident engineer. The client's process specialist was based in Vigo, Spain, although the executive decision-making was made through a subsidiary.

## The brief

The expanding and changing process requirements led to a dynamic brief and ongoing construction activity over the three years from 1990 to 1993, in which good documentation and regular reporting was essential. The brief required the establishment of a fish factory on a greenfield (or rather bare granite) site on the edge of Robert Harbour, just beyond the northern outskirts of the town.

*Phase 1*

The initial facility was to comprise:

- A 1500m$^2$ packaging hall, fully serviced and air-conditioned to 14°C
- A 600m$^2$ x 8m high cold store to operate at -25°C
- A cold store air lock
- A 1500m$^2$ store building, insulated and constructed for easy future conversion to a packing hall
- A refrigeration engine room
- Staff ablutions and amenities
- A single-storey administration building (designed for two floors)
- Workshop facility.

7. Fish processing.

*Phase 2*

A few months after completing construction of Phase 1 in February 1991, Pescanova requested Arups to proceed with:

- A causeway and 130m long jetty to accommodate vessels up to 7000 tonnes (to avoid double handling of fish and transport to and from the main Lüderitz harbour)
- An ice-making plant, initially of 50 tonnes capacity per day
- Storage facilities for 150 tonnes of flake ice
- A 40 tonnes/hour ice discharge blow line
- A wet fish chill room for holding the product before processing
- A covered off-loading and crate store building
- An additional refrigeration engine room
- Conversion of two packing halls to wet fish processing
- An additional floor on the administration building
- Seawater intake facility and UV seawater treatment
- Forklift maintenance and battery charging workshops
- Extensions to the staff ablutions
- A new laundry.

Further facilities had been added subsequently as an extension to Phase 2:

- A treatment plant and boiler house in which fish offal is dried, milled and bagged
- A temporary seawater pumphouse
- A stevedores' ablution and amenity facility.

All the above were completed for the official opening in August 1993.

*Future development*

During the initial design of Phase 2, a number of circumstances persuaded the client to ask Arups to carry out new masterplanning studies. These were because:

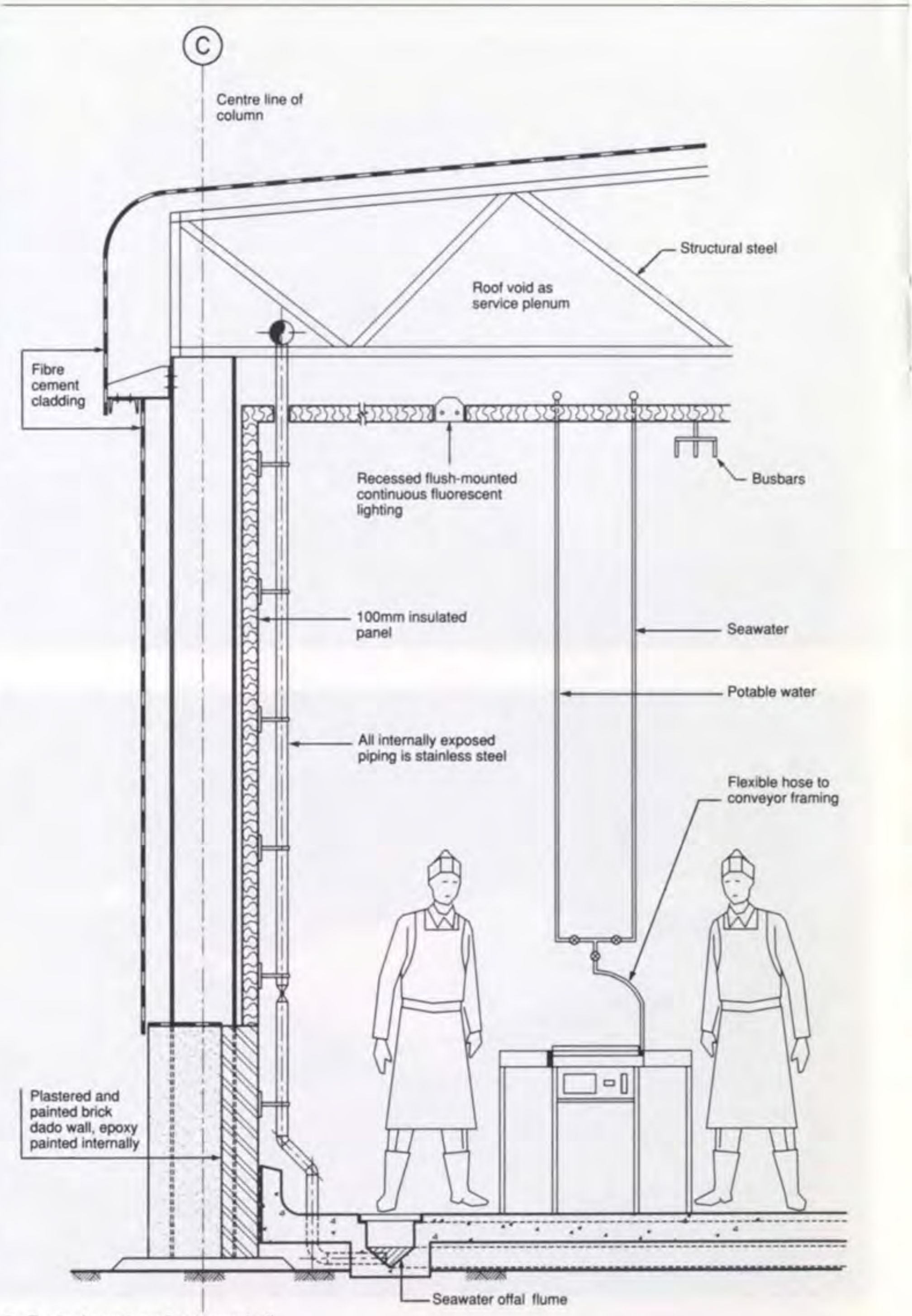
(1) There were already signs of recovery in the fish stocks.

(2) The client was considering and subsequently purchased the adjacent site to the north.

(3) If further process facilities were to be built, there would be a substantial increase in piped services, power, and refrigeration requirements.

(4) Wet fish processing, being highly labour-intensive, required substantial increases in staff amenities.

A number of planning options based on 'what if' scenarios were produced, assuming varying increases in fish quotas. These have assisted Pescanova to determine the broad direction of future process requirements and thus future construction. In fact, the results of these studies were used to locate the later Phase 2 buildings on the new property. In anticipation of possible future requirements the client authorized modification of the model of the facility to include Arups' proposed development for the new site.




8. Typical section of process hall.

9. Process hall in operation.

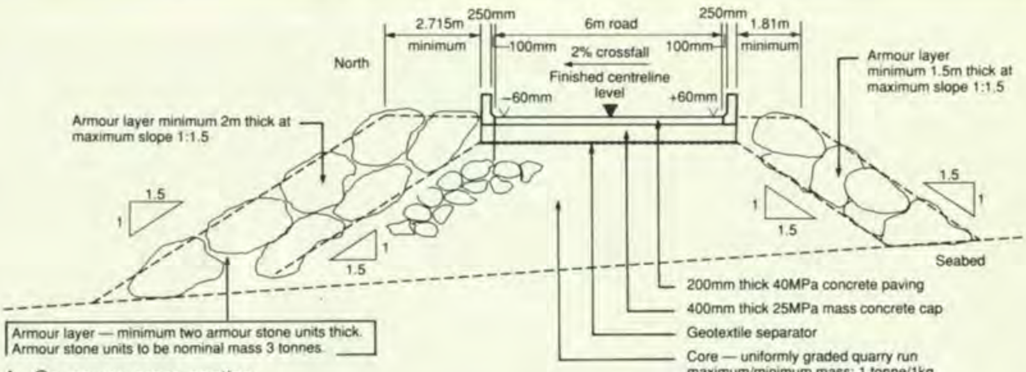
## The jetty and causeway

It was determined that a rock/rubble access causeway (Fig. A) was the most economic in the shallow water zone up to 5m deep. The local authority required an independent desk study by the South African Council for Scientific and Industrial Research to determine what effects such a causeway would have on the local marine environment. Having obtained clearance on this aspect Arups held discussions with the client's fleet captain and the port captain to resolve the jetty orientation and berthing procedures.

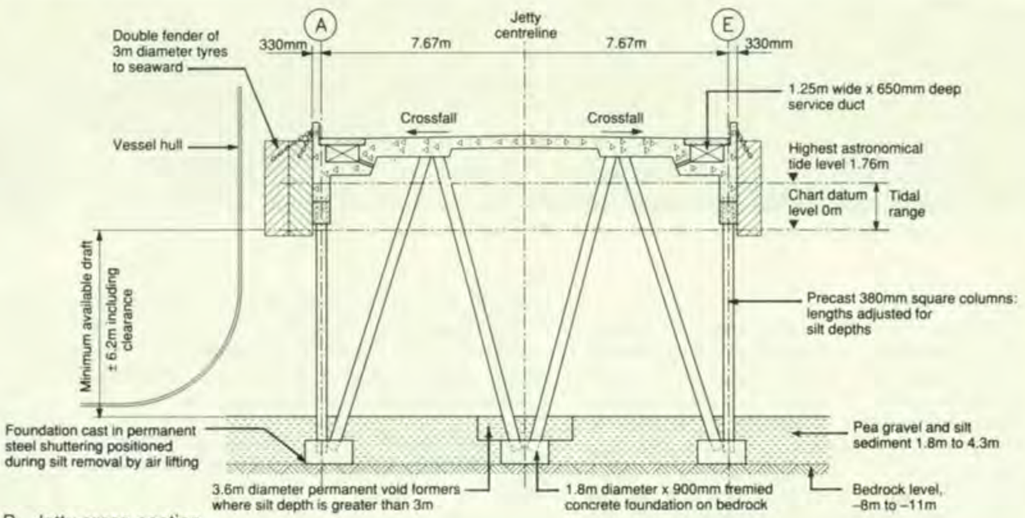
Inevitably, the orientation of the jetty ended up as a compromise, giving preference to berthing into the very dominant southerly winds. Although the harbour is reasonably well-protected, the jetty is exposed to swells from the open sea to the north-west, which means that it may not be operational 100% of the time. In fact the over-riding design forces applied to the jetty are from this condition and allow for a side wave effect on a berthed vessel equivalent to a force of 11 tonnes/m. Bollard pulls of 30 tonnes were also designed for.

Beyond the causeway section, the jetty comprises precast concrete columns in rows at 5m centres, with a precast beam and in situ slab structure between. The jetty construction resulted from a contractor's alternative proposal at tender stage and uses a cantilever erection rig and minimum mass precast components to limit hoisting requirements. The typical cross-section (Fig. B) indicates how the precast columns and cope bottoms were integrated into the remainder of the in situ concrete construction. The fact that there were no uplift forces on the columns allowed simple foundations to be cast directly on solid rock. The substantial silt layer (up to 4m) was retained by permanent steel shutters air-lifted into place whilst carrying out silt removal by the same method.

The 16m jetty width was determined from turning circle trials with tractor/trailer combinations, and the length of the first phase provides mooring for a 105m long reefer.




A. Causeway cross-section.




B. Jetty cross-section.

C. The completed jetty.

Possible work in the near future may include:

- Commissioning of a second wet process hall including additional plate freezers
- Additional ice-making: total 100t/day
- Additional ice storage to total 300 tonnes. This requires the full refrigeration equipment to be installed in the second engine room.
- A packaging material storage building
- Extension of the jetty to a final 210m.

### Building design

Planning of the facility was developed in conjunction with the client's process engineers to minimize the effects of the solid granite covering the site, and to provide a hygienic, straight through, product flow that does not 'back track' on itself.

The major buildings at the facility were the process halls (designed to EC standards) and the cold store, which are insulated with prepainted zinc-coated steel panels separated with varying thicknesses of polystyrene. These are supported by galvanized structural steel framing, each being clad with fibre cement to minimize corrosion and the effects of wind-blown sand. The steelwork was fabricated elsewhere at rates substantially lower than those quoted locally. On all the many contracts the client took a very pragmatic attitude and was prepared to 'sponsor' Namibian industry if it was within 10% of the lowest price. He also insisted on maximum use of local labour where non-Namibian contractors were involved. All other building construction incorporated load-bearing brickwork using cement bricks manufactured on site.

### Conclusion

The project has been challenging, especially in relation to interpreting the client's needs into a practical brief and planning solution, in working at long range in such a remote part of the continent, and in such a unique environment. It also gave the Arup team an insight into a fascinating industry from which it is hoped further commissions will arise. Special recognition must go to the client project team for their valued contribution: A. Tordesillas, Pescanova CEO; Capt. J. Nimo, Operations Manager; G. Mantecon and V. Garcia-Echave, Process engineers.

**Credits**

*Client:*
Pescanova SA

*Principal agent, civil, structural, mechanical and electrical engineering, and quantity surveying:*
Arup Namibia
Frank Louw (project co-ordinator), Jan Hofmeyr (structural), Pat Hing (mechanical), Ed Schmidt (electrical), Bruce Bulley (geotechnical), Paul Monk (civil), Andrew Hakin, Donie O'Loughlin (REs)

*Architect:*
Kerry McNamara Architects

*Refrigeration engineering:*
Worthington-Smith and Brouwer

Phase I construction stage only:

*Quantity surveying:*
Wicks, Goosen and Pineo

*Mechanical and electrical engineering:*
Juliohn Taylor Consulting Engineers

*Contractors:*
International Construction (Pty) Ltd (Phase 1)
Salz-Gossow (Pty) Ltd (Phase 2)
Marine Civil Namibia Ltd (Jetty)

*Illustrations:*
1, 4, 8, A, B: Elaine Lawrie; 2, 5, 6 Photos: Toni's Studio; 3 Photo: Arup Namibia; 7, C Photos: Donie O'Loughlin; 9 Photo: Frank Louw.

# The Oxyco development, Harare, Zimbabwe

Lotte Reimer

▲ 1. Birmingham Road, Phases 1 & 2, with part of the Glasgow Road site.

## Introduction

Oxyco Gases is part of the Oxygen Industries Group, Zimbabwe, a subsidiary of the British Oxygen Company Group (OCG). Oxyco is the main supplier of gases to the Zimbabwe market, being sole producer of acetylene, nitrogen, argon, and nitrous oxide. It also provides oxygen for all the country's users except Zimbabwe Iron and Steel Co., which has its own suppliers. Furthermore, Oxyco imports and distributes 100% of the carbon dioxide and 30% of the liquid petroleum gas (LPG) used in Zimbabwe.

Production of oxygen, nitrogen, argon and nitrous oxide is centered in Gweru and then shipped the 200km to Harare for distribution in the Mashonaland area. Distribution was previously from Oxyco's Glasgow Road site, which also housed the existing dissolved acetylene (DA) and hydrogen plants.

LPG and carbon dioxide were stored and filled into cylinders at Manchester Road, 4km away.

With rising demand for their products in Harare and Mashonaland generally, Oxyco embarked on further development. The main part was to be at the new 1.7ha Birmingham Road site, divided by a railway siding from the Glasgow Road site (Fig. 2).

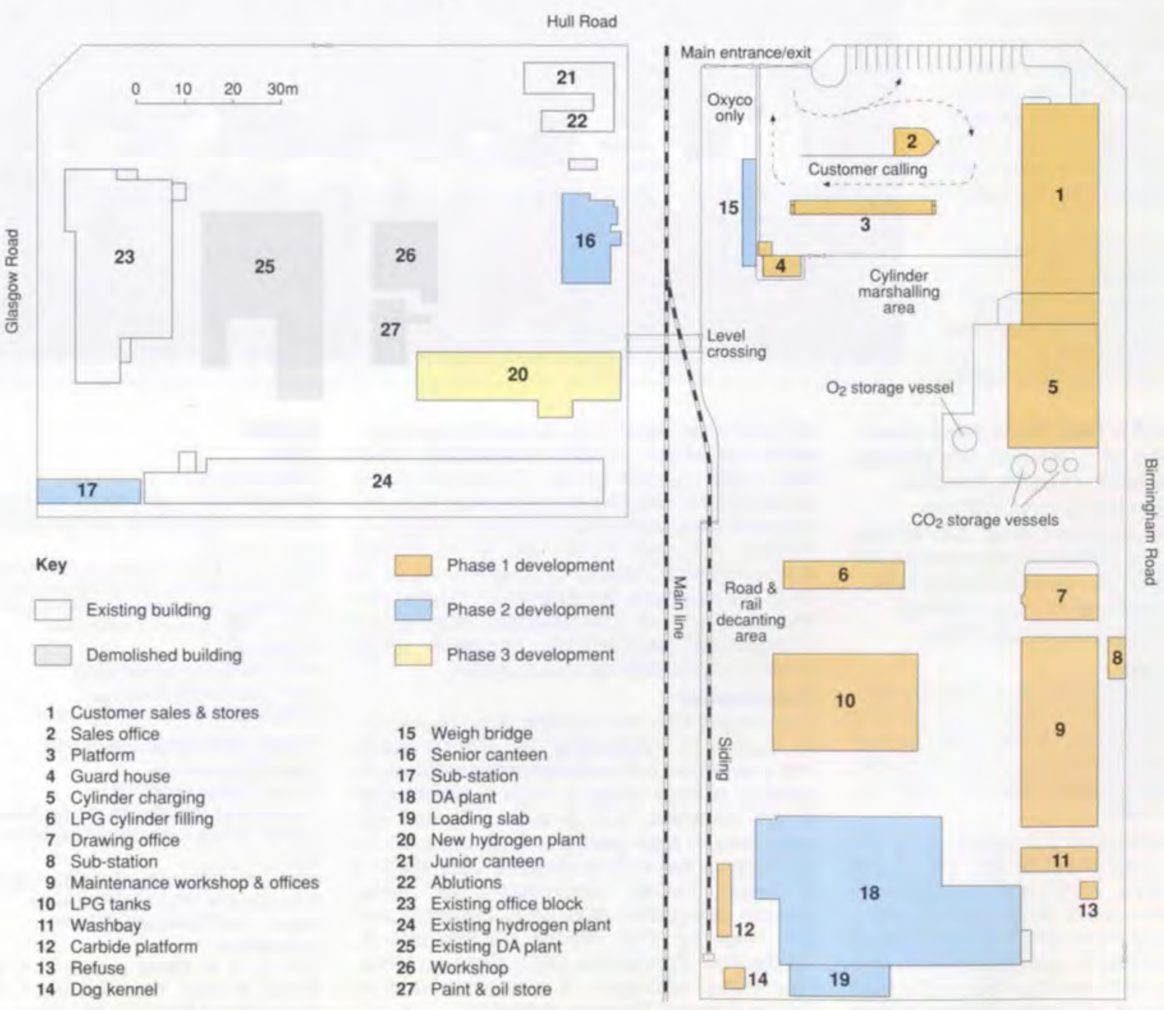
The main objectives were:

(1) to improve customer calling facilities

(2) to update and increase production and distribution of gases

(3) to concentrate all gases functions in one area.

In 1986 Oxyco appointed Ove Arup & Partners as principal agent and multi-disciplinary consulting engineers for the development. Arups were to lead the professional team of architect Rob Cobban and quantity surveyors Nudds, Mahachi McCormick. Tower Construction successfully tendered for the main contract.




2. Site plan.

▲ 3. Road and rail area sprinklers.

▲ 4. Rail decanting area sprinklers.

▲ 5. LPG pipes with check-fire tubing.

**Project description**

The brief was to manage the project and to plan and design the site, including civil work, site services, traffic flow, all buildings and building services. All this had to be done in close liaison with Oxyco, responsible for the process design. Phase 1 included the following elements:

- customer calling area
- cylinder charging building
- drawing office
- maintenance workshops
- LPG storage and cylinder filling facilities
- water and electrical reticulation
- fire protection and alarm systems
- rail siding
- surfacing and drainage of the site.

After a site start in May 1987, all this was in full operation by March 1989 except for the LPG tank area which was commissioned in June 1990.

Phase 2 consisted of a new dissolved acetylene (DA) plant and a 60-tonne weighbridge, both at Birmingham Road; at the same time a new substation was constructed at Glasgow Road. Phase 2 started in July 1988 and the DA plant was commissioned in May 1991. Phase 3, a new hydrogen plant at Glasgow Road, began in January 1991 and was commissioned in November 1992.

Also included in the project was a total renovation and upgrading of the stormwater and sewerage system in Glasgow Road. The total project value at 1992 cost is approximately Z$35M (US$6M).

**Civil and planning works**

The Birmingham Road site had to be cleared of the remaining structures and debris left by the previous occupier before the new facility could be planned and developed. Previously, cylinders had been manually handled for filling and horizontally loaded at a site which incorporated production, storage, filling and customer calling. For improved safety and security, however, Oxyco now decided to separate the latter from the other production functions. Cylinders were now to be stored vertically on pallets and moved by fork lift trucks, reducing the number of back injuries, crushed fingers and damaged cylinders.

The critical factor for the customer calling area was traffic flow. Due to the limited size of the site, the area had to be planned very carefully to cater for trucks of all sizes without wasting space, several proposals being considered before the present 'one-stop' solution was chosen. Customers drive in through the customer area gate, park alongside the service platform and, while paperwork is dealt with in the centrally-positioned sales office, their empties are replaced with full cylinders. They can then drive straight off and out of the site without turning round (Figs. 1, 2). Streamlining of the process has reduced the time customers spend collecting gas by more than half.

A parking area is provided for other customers who have business with the gases and welding sales office.

Since the area was to be in constant use by forklifts, cars and trucks, concrete hardstanding was chosen for durability.

The production area has a separate entrance from Hull Road and a driveway incorporating the 22m long, 60 tonne capacity weighbridge. Again traffic flow was carefully planned in an area used both by forklifts and big road tankers, as well as being connected to the Glasgow Road site by a railway siding crossing. This area was also surfaced with concrete hardstanding.

Waste water, mainly from the vehicle wash bay and the DA plant, is led via separators to the municipal sewer system. This is a major environmental improvement from the old DA plant site which had no such provisions. Waste water from the new Pase 3 hydrogen plant — small quantities with a low caustic soda concentration — passes through neutralizing tanks to the municipal sewer. all these facilities are designed to strict environmental requirements.

Oxyco's supply of LPG is transported by road and rail. A siding was constructed from the main line to the rail decanting area, laid to a fall of less than 1:600 to ensure that tank cars do not run away if inadvertently parked without setting the brakes. As an extra safety measure the siding terminates with a sand drag and a buffer stop.

The rails in the siding are insulated from the service siding rails, bonded together electrically, and connected to an earth pin to minimize the risk of a static electrical spark occurring.

**Mechanical**

The mechanical services include water reticulation, cooling water for process equipment (DA plant and hydrogen plant) and ventilation for the DA plant. Fire protection throughout the site, however, was the most significant part of the mechanical design.

Safety was the paramount consideration. The greatest potential hazard is the 190 tonne capacity LPG tank farm and the safety precautions in the design have made it one of the most advanced and safest of its kind in the world.

The tank farm was designed to:

(a) receive and unload both rail tank cars and road tankers into the bulk storage vessels

(b) fill portable handigas cylinders

(c) fill the road tankers which distribute LPG gas to bulk customers.

Accidents are most likely to occur during decanting of the LPG from tankers, so stringent safety precautions have been introduced. The decanting pipework is embedded in heavily reinforced concrete walls so that it cannot be dragged out of the sidings in a tow-away situation and is provided with emergency shut-off valves. This ensures that in the unlikely event of such an accident while the tank is being decanted, the flow of LPG out of the tank farm and its pipework system will be stopped immediately and no major spillage will occur.

Both the rail and road decanting bays are served by a deluge system. On activation, sprinklers drench the tank cars with approximately 10litres/m$^2$ per minute (Figs. 3, 4). The system is automatically operated in the event of a fire by a check-fire system, the first of its kind in Zimbabwe, which comprises a nitrogen-filled plastic detector tube strapped to the LPG pipes and strategically positioned round the central valves at the decanting points (Fig. 5). The plastic tube will melt at a certain temperature, triggering the deluge valve by loss of nitrogen pressure. The system can also be manually activated and each segment of the decanting bays can be isolated individually to conserve water and redirect it to where it is most needed.

In both road and rail decanting areas granite chips in concrete beds act as heat sinks to evaporate rapidly any liquid spillage.

The same system of heat sinks was designed for the storage vessel area. The tanks are mounted on reinforced concrete foundations, in an area specially designed to channel any major spillage away from the centre of the individual tanks and sloped to a catchment pit filled with granite chips, at one end of the tank area. The individual tank areas are separated by low walls to prevent spillage from one tank spreading to the other tank areas. This system will minimize the spread of fire should a spillage occur.

Protection of the tanks themselves was a major concern, water alone being insufficient since the supply required could not be guaranteed from the municipal fire mains. After several proposals the best solution was found to be a combination of fireproof insulation and water spraying. Pyrocrete insulation, to reduce heat input from any fire near the tanks, was plastered onto their surfaces over fine metal mesh to hold it in place. To back up this insulation system four fixed monitors were installed to cover the tanks, rotating through 360° horizontally and from below horizontal to vertical. The nozzles, which deliver a constant volume of water, are variable between a single solid jet to a fog mist position, giving excellent flexibility of use. Again, they are the first of their kind in Zimbabwe and most spectacular in operation (Figs. 6, 7).

The monitors are automatically activated by a check-fire system as in the decanting areas, with the tubes strategically located on control valves on the tanks themselves. They operate separately from the other check-fire system and can also be operated and isolated manually.

The LPG cylinder filling building is protected by a deluge system. Upon activation by heat sensitive bulbs, the entire building is immediately sprinkled with large volumes of water.

The whole LPG area was designed to the most stringent safety requirements from the latest American and British Standards and the BOCG Technical centre, New Jersey, who recently praised the design as one of the newest and safest LPG tank farms in the world.

**Electrical**

The sites are served separately by Zimbabwe Electricity Supply Authority (ZESA) with duplicate incoming feeders at 11kV terminating in a sub-station on each. They provide a maximum demand load in the region of 2.4MVA.

Because of the development proposals for Glasgow Road the existing sub-station, inadequate for future demand, had to be demolished. The new sub-station had to be established prior to demolition, which presented many complexities for transfer and rerouting of installed distribution cables, with the brief to maintain the existing plant and facilities in operation. All this was successfully achieved.

From each of the sub-stations an underground distribution cable network has been provided in the form of a medium voltage radial supply serving buildings and process plant. The underground pipe duct system incorporates draw-in pits with removable covers to allow access into the system.

Other facilities include a signal cable network between all of the buildings, comprising fire and security alarm systems where signals are relayed to the Guard House to monitor alarms in any of the buildings. Also included is an underground pipe duct network for telephones.

The installations serving process areas and associated plant are to international flameproof standards because of the high risk of explosion. These include the power and control systems required for process plant operation, together with plant shutdown facilities in emergency situations.

Externally, floodlighting has been provided throughout the traffic areas comprising 70W SON lanterns wall-mounted on buildings. The general amenities and administration buildings have been provided with emergency lighting using self-contained luminaries along all exit routes.

These fittings illuminate automatically on mains or sub-circuit failure and provide three hours' duration of emergency lighting.

▲
6 & 7. Monitors in action.
▼

8. Sprinkler support portals, LPG decanting area.
▼

**Building structures**

The buildings were designed to be functional, aesthetically pleasing, and economical. Use of locally available materials to minimize foreign exchange was a governing factor. They were mainly designed as reinforced concrete frames with brick infill panels and structural steel roof trusses with asbestos cement roofing sheets. The structural steelwork was designed using local sections, the only imported item being chequer plate flooring for the DA plant filter press floor.

A number of reinforced concrete portals were designed to support the pipework and sprinkler system for the LPG road and rail decanting area, which was designed to accommodate the largest road tankers and tank cars operating in Southern Africa (Fig. 8).

The new DA plant, incorporating a carbide store and an acetone store, had very stringent safety requirements. The former had to be absolutely waterproof (calcium carbide reacts with water to produce highly explosive acetylene) and was covered with a concrete slab as well as being closed off from the other areas of the plant. The carbide loading platform was covered, stormwater drains were constructed on both sides, and a low hump was installed across the doorway to ensure that no water would be able to enter the store under any weather conditions. Flameproof areas like the acetylene cylinders' filling room and acetone store were sealed off from the compressor motor room and other areas with potential 'spark danger'.

**Conclusion**

The new development has resulted in a great improvement to Oxyco's customer service, both in terms of increased output and efficient service. It has also led to vastly improved working conditions for Oxyco's staff. With the fire protection of the LPG area in particular and the facility in general, the Harare site is now among the safest production and distribution works in the world.

**Credits:**

*Client:*
Oxygen Industries Group (Pvt) Ltd, Zimbabwe
*Project manager; design team leader; structural, civil, electrical and mechanical engineers:*
Ove Arup & Partners Zimbabwe Stuart Perry, Lotte Reimer (project management, and structural), Andy Marks (civil), Ignatius Dube (structural), James Rooney, Chris du Cane, Andy Howard (mechanical), Chris Wood, Steve Done (electrical)
*Process engineers:*
Oxyco
*Rail engineers:*
Civil Technics
*Architect:*
Rob Cobban Architect
*Quantity surveyor:*
Nudds Mahachi McCormick
*Hydrogen production unit:*
Bamag GmbH
*Main contractor:*
Tower Construction
*Specialist contractor (Phase 2):*
Quick Freeze
*Photos and illustrations:*
1, 3, 4, 6, 7: Lotto Reimer; 2: Kris Buglear; 5, 8: Margaret Waller

# Düsseldorf Tower

**Designers: Arup Associates in association with Eller Maier Walter**

Alastair Gourlay    Peter Warburton    Terry Raggett

1. (above): Site plan.

2. (below): North-south section.

Arup Associates' recent proposal for a new high-rise building in Düsseldorf was designed to minimize the impact of the development on the environment. Prepared in response to an invited competition to design an energy-conserving urban office tower, the scheme proposed a 20-storey block planned around a raked atrium.

The site, in the heart of the city on Rheinferstrasse am Labnweg near to the State Parliament buildings and overlooking a large city park, is located above a major road which runs under the site in a tunnel. Consequently the plan of the building is organized with two 12m wide wings of office space aligned on either side of this tunnel with an atrium between. By planning the atrium over the tunnel and supporting the atrium roof off each of the office wings, it is possible to avoid imposing structural loads within the zone of the underground tunnel while creating a daylit hall at the centre of the building.

The two wings of offices are linked by a core housing services, main entrance, lifts and stairs. In section the office floors rake back with these cores acting as buttresses. The whole glazed terraced building was designed to reflect a 'green' upward curve at the end of the Park.

Exhaust fumes and noise from the entrance to the road tunnel precluded openable windows on one face of the building. As this was also the south-facing elevation, the design created a solid façade which was utilized as an energy source.

The façade incorporated solar collectors facing south. Behind the solar collectors are two towers containing phase change salts: a mixture of selected chemicals which changes from a solid to a liquid and vice versa around a prescribed temperature. This stores and releases energy with small changes in temperature, in contrast to systems which are normally activated only by large temperature changes. One was to be regenerated by the solar collectors at a phase change temperature of 30°C and the other by a co-generation plant at a phase change temperature of 50°C.

The building was designed to be naturally ventilated with opening windows on the east and west assisted by the stack effect of the atrium. However, it was also designed to provide the facility for a considerable number of cellular offices. Consequently each cellular office was ventilated by using a separate hollow core plank ensuring that cross ventilation was not interrupted by a central corridor.

In extreme winter and summer temperatures the windows in the offices and cross-flow ventilation openings are closed and a mechanical plenum heating and ventilation system used. This makes it possible to recover heat, a technique which is not normally possible with natural ventilation. In the extreme summer condition, the ventilation plant introduces cool night-time air through other hollow core planks. This cools the building for the following day. In the extreme winter condition the plenum heating plant uses heat from the solar salt store and the co-generation salt store depending on demand.

The east and west facing façades were designed to incorporate a system of external rotating screens. These provide sunshading as well as night-time insulation. They can also respond to the differing requirements for daylight throughout the year.

The scheme was placed second in the competition, which was won by the local Düsseldorf architect, Ingenhoven Overdiek Petzinka und Partner, who is now working on the detailed design with Ove Arup & Partners.

3. Model: south façade

4. Model: north façade

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