THE ARUP JOURNAL

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SUMMER 1985

THE ARUP JOURNAL

Vol.20 No.2 Summer 1985
Published by
Ove Arup Partnership
13 Fitzroy Street, London W1P 6BQ

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Front cover: Leslie & Godwin building: main office entrance (Photo: Peter Cook; Designed by: Arup Associates)
Back cover: Ronald Jenkins

Leslie & Godwin, Farnborough

Arup Associates
Group 5

Mike Bonner
Terry Raggett

The brief

The Leslie & Godwin Group commissioned Arup Associates in September 1978 for the design of an owner-occupied office building totalling about 9,500m^2 at Farnborough, Hampshire. The brief required a mixture of deep and shallow office accommodation with lettable commercial space at ground floor level. Outline proposals were approved by Leslie & Godwin in December 1978 but because of reorganization within their company, the scheme was temporarily halted.

In March 1980 ownership of the proposed building was acquired by the Imperial Group Pension Trust Ltd. who, through their agents Richard Ellis, amended the brief to one considered more suitable for a speculative building. The office space was to be of a constant width of not more than 18m which could incorporate enclosed offices at the outer perimeter and also capable of being subdivided into separate lettable areas of between 600m^2 to 850m^2.

The dining area was required to cater for a total of 450 people in three separate sittings and was to be provided with separate coffee lounge and bar.

The ground floor had to include the pedestrian right-of-way developed into an enclosed shopping mall with as much commercial lettable space as possible on each side. In addition, covered space for 20 cars was required as part of the site purchase agreement.

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The office entrance was to be separate from the entrance to the shopping mall and to have a clear identity for visitors to the building.

The client also requested that special attention was to be paid to the problems of traffic noise and solar gain and to the long-term running costs.

The site

The site is one acre of level land with the northern boundary enclosed by the 5.0m high red brick wall of the Kingsmead Shopping Centre. Although predominantly a two-storey development, it also includes an eight-storey office block and a multi-storey car park which dominate the scale of the surrounding area.

The site is bordered by roads on the other three sides; the A325 Farnborough Road runs parallel with the eastern boundary linking Farnborough, Aldershot and Farnham with the M3 motorway, and to the south are two extensive public car parks and a large roundabout. A few isolated mature trees offer a little relief to the predominantly hard, noisy surroundings.

An existing public right-of-way connected the shopping centre with the bus stop on the southern boundary and divided the site into two and, although the site was left over from the Kingsmead development, it is the centre of focus for people entering the centre by bus or from the public car parks to the south, and for motorists coming down the hill into Farnborough on the A325 from Aldershot.

The Royal Aircraft Establishment is located about three quarters of a mile away towards the south-west and low flying aircraft pass quite close to the southern boundary when they approach the runway.

The design

It was clear that the new building would have considerable impact on its surroundings because of the key position of the site. We therefore decided that it should contribute an element of order and visual interest to the undisciplined and rather drab character of the neighbourhood.

The solution we adopted was a four-storey 'U'-shaped office building which closely follows the southern site boundaries and which abuts a high brick wall to the north separating the new development from the shopping centre.

Because of the site environment and the need to protect the office space from traffic noise and solar gain, it was considered essential to seal the outer perimeter and therefore to air condition the interior. This led to the structure and the elevation playing a major part in the environmental services design concept for the building.

All office spaces have raised floors for the distribution of computer cabling as well as electrical and telephone services and this floor void is used as the supply air plenum for conditioned air supplied through floor-mounted air diffusers.

The outer perimeter of the offices is enclosed within a double skin elevation. The outer skin is totally glazed with bronze tinted glass to provide consistent, easily maintainable weather protection. This skin is facetted so that its reflective surface responds to variations in light and changes of view. At first floor the skin projects to form a glass canopy over the pavement.

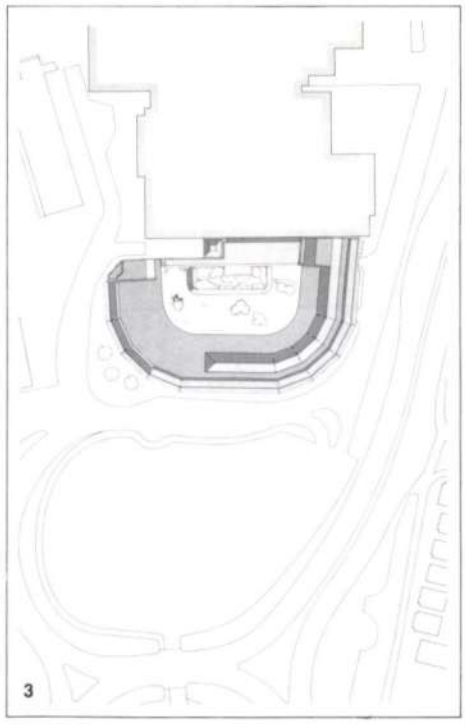

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Fig. 1
Detail showing the double skin

Fig. 2
The south elevation overlooking the car park

Fig. 3
Site plan

Fig. 4
Office interior

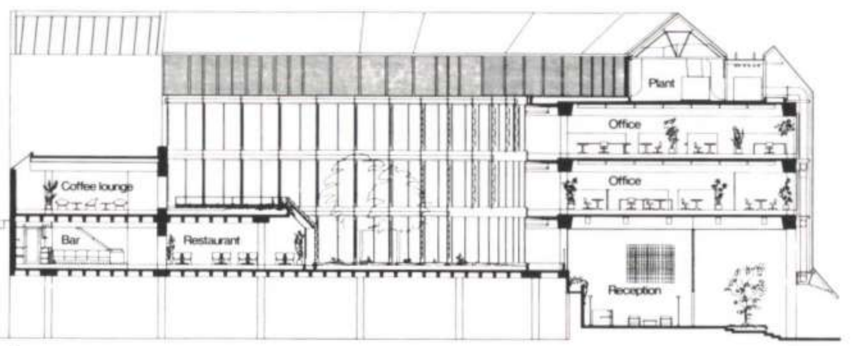


Fig. 5
Section

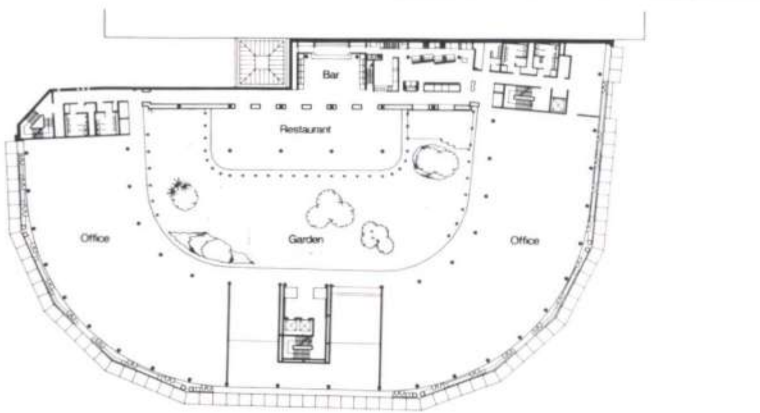


Fig. 6
First floor plan

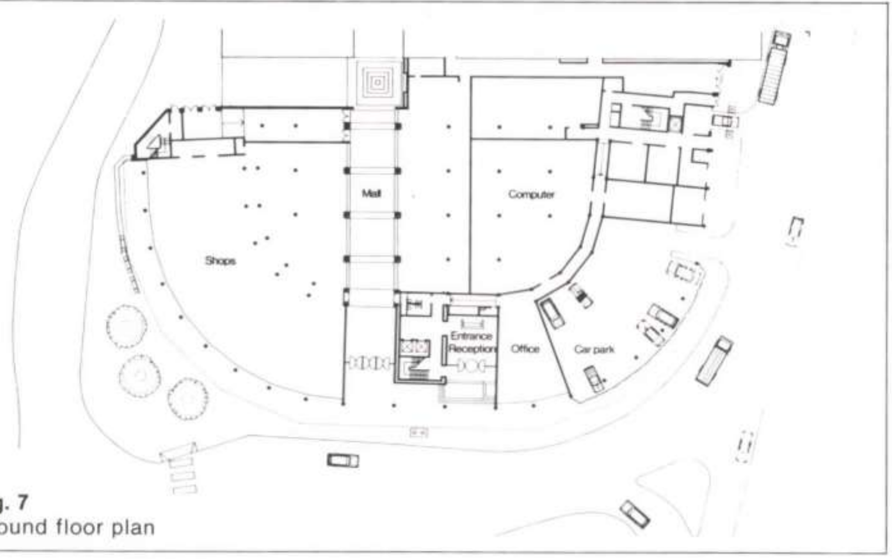


Fig. 7
Ground floor plan

The inner skin consists of both glazed and solid panels which are interchangeable to suit varying office layouts. The 1m wide space between through which the main air supply ducts run, contains motorized venetian blinds with finely perforated blocks to filter sunlight to the interiors.

The 'U'-shaped plan encloses a garden at first floor level. Main circulation at each level is along the shorter garden elevation with direct access to the open office spaces. Enclosed offices are located along the outer perimeter where they have their own outlook and are not disturbed by the pedestrian route. These private offices are formed from glazed or solid partition panels similar to those of the inner skin with unframed glazing at high level fitting into grooves in the ceiling beams. At first floor garden level the main circulation route connects the three office cores to the dining area which is built against the brick wall enclosing the garden on the north side. Behind this wall are the bar and servery with the coffee lounge and kitchen on the level directly above.

The ground floor encloses a pedestrian mall with commercial lettable space on both sides and accommodates the main office entrance, computer suite, covered car park, stores and some of the mechanical and electrical plant. The office entrance is a double height space which opens up to the first floor pedestrian route and allows glimpses of the shrubs and trees in the garden beyond. It is located to the east of the pedestrian mall and is separated from it by the central stair core. The loading bay is in the north-east corner of the plan with direct access to the goods lift which serves all the office floors and the kitchen at second floor level.

Although the building has a 'U'-shaped plan it is basically a linear structure in which concrete ribs span between concrete beams. The surfaces of the ribs are painted in the offices and are evenly lit by specially designed luminaires. This has the effect of making the ceiling float and appear higher than the actual dimension of 2.4m from finished floor to soffit. The main stairs and lifts are located at the centre of the 'U' with escape stairs and toilets at the ends of each arm. Between the service cores on the three upper floors are constant 14.40m wide office spaces giving discreet lettable areas of approximately 800m^2.

Major elements of service plant are accommodated in the high level plantroom which is located on the roof between the central and eastern service cores. The plantrooms connect to the space between

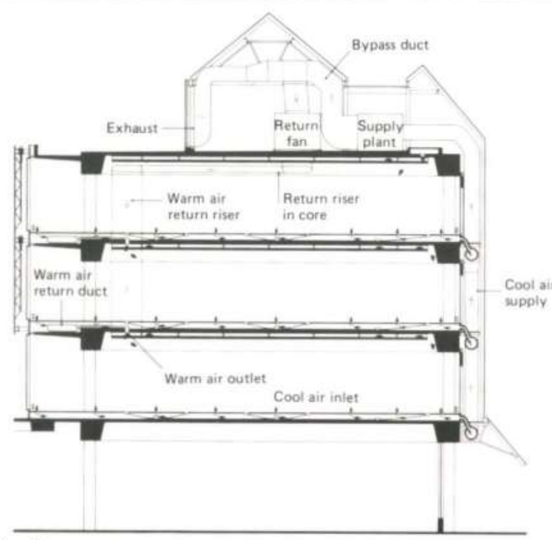


Fig. 8
Cross-section showing air distribution

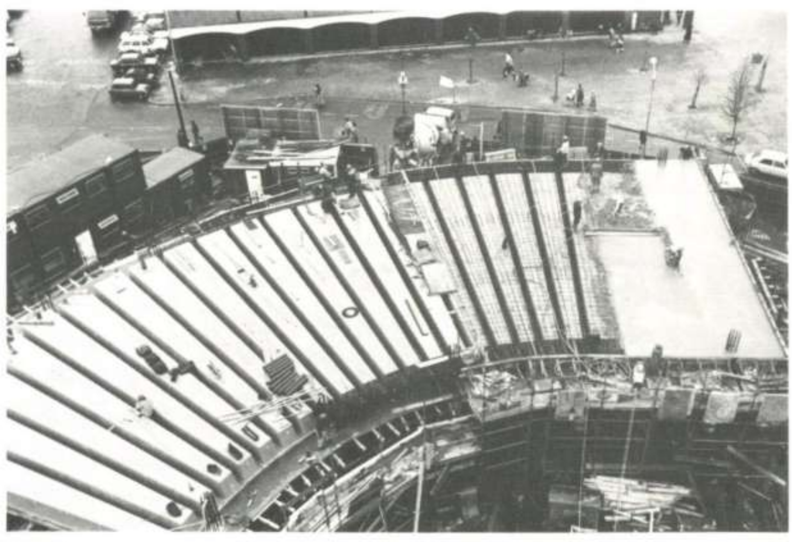


Fig. 9
Radial floor beams under construction

the inner skin and outer skin which is used for the distribution of supply air ductwork and for maintenance access to the glass and blinds. The ductwork has a bright red stelvetite finish which can be clearly seen behind the glass skin.

The bronze glass outer skin as well as projecting at low level to form a canopy is raked back at high level to enclose the plantroom on the roof. In order to resolve the junctions resulting from this geometry, Pilkingtons and Doulton Glass developed a new system of glazing for the building which is now known commercially as the Pilkington *Planar* System. Sheets of 10mm bronze armourplate glass, 3.6m high × 1.8m wide, are held in place against aluminium mullions by six 6mm diameter countersunk stainless steel bolts. These bolts pass through pre-drilled holes in the sheets and are connected to the glass by a system of specially designed gaskets and washers. Only the bolts at the top corners of each sheet carry the vertical load of glass, the remainder being used solely to transfer horizontal wind loads to the aluminium mullions. This method of fixing allowed the glass sheets to be considered as separate plates which could be located in space to achieve the required facetted angles, and the gaps between were then simply sealed with gun-applied silicone sealant. The erection of the glazing proved to be relatively easy and the whole system provided a simple solution to what could have been a complicated problem.

The rear elevations of the offices, which face the garden, are sealed with a more conventional system of single, clear, toughened, glass sheets in aluminium frames with solid, insulated spandrel panels at each floor level and at the roof. Motorized blinds are also provided on the east and west segments of the elevation to control glare from morning and evening sun.

Structural design

The section drawing shows the principal structure to be arranged as a single portal frame, four storeys high.

It is built entirely of in situ concrete and comprises ribs spanning 14.4m between perimeter ring beams, which are in turn supported on circular columns at either 5.4m or 7.2m centres. The curved section of the plan has radii of 14.4m and 28.8m to the inner and outer ring beams respectively. The ribs are spaced at 1.8m intervals along the outer perimeter closing up to 0.9m along the inner perimeter. Their depth was determined more because of their integration with the lighting/extract duct fitting than by structural considerations, and could have been decreased significantly by taking advantage of the prestressing techniques finally chosen for this structure. However, their effectiveness as 'concrete lamp shades' would have been compromised by so doing.

At an early stage in the design a decision was taken to prestress (post-tension) the ribs for a number of reasons:

Firstly the relatively wide span and single-bay configuration produced rotations at the columns which influenced their size disproportionately to the axial loads carried. By prestressing the ribs and considering the tendon profiles, column moments could be adjusted and were in fact greatly reduced. By load balancing, the long-term deflection of the ribs became negligible and pre-cambering unnecessary.

There were further advantages to be gained such as reducing reinforcement congestion, but more importantly, by stressing the tendons in two stages, the formwork and staging to the ribs could be removed after about three days. This was particularly important since the ribs are exposed and therefore required particularly high quality, expensive GRP moulds. The moulds were of trough profile and, for ease of handling, made in five sections from a one-piece master. Each set of moulds was marked to ensure their correct match on site, where they were butted together and carefully aligned on the staging. They were then bolted together using foam strip between the butting faces, but no tape was used as it was considered that this would draw attention to the joints when the ribs were finally painted. All post-tensioning hardware, fixing and stressing was by PSC *Slabstress* using one 7k/13 tendon per rib with recessed live end anchorages located in the external face of the outer perimeter beam. The tendons were fully bonded, of parabolic profile, and stressed in two stages at three and 14 days respectively.

The fibreglass moulds were by Barnes Plastics and the superstructure subcontractor was Gleeson.

It is worth noting yet again that where a project contains some unusual aspects, these usually perform well since they are given the attention they deserve. In this case the post-tensioning and construction and alignment of the formwork all performed smoothly, accurately and rapidly.

Substructure

A water table about 1.5m below ground level, Ph values typically around 3.5, and a site overlain by nearly 1m of peaty clay ensured that the substructure required some thought.

The subsoil was basically silty sand overlaying gravels and because of the close proximity of existing buildings we would have considered flight augered, grout intrusion piles (eg: Dowett *Prepakt*) had it not been for the acidity of the ground. We finally opted for driven in situ end bearing piles with rigid PVC tubes encasing the shafts. This at least seemed to provide a solution to the ground water and acidity problems, but raised another problem – vibration.

The appointed piling sub-contractor, Frankipile, had piled the adjacent site without undue vibration problems, but monitoring during our trial pile test indicated that we would have to modify the driving techniques in order to limit ground-borne vibrations. This was accomplished by reducing the mandril drop at various stages during driving, whilst Arup Acoustics monitored the effect upon vibration at various locations using their magic black boxes.

Human beings are remarkably sensitive to vibrations and it wasn't too difficult to calibrate the RE's dentures with Arup Acoustics' swinging needles, thus avoiding the need for constant electronic monitoring.

There were three main areas where vibration was a potential problem:

(1) Domestic houses about 100m away where vibrations evoked the understandable concern and natural suspicion of the householders.

These houses were surveyed before and after piling operations. No damage was found but one resident was particularly concerned because the vibration was causing waves in his fish tank, and his fish were beginning to look a bit sea-sick.

(2) A multi-storey building, with long span and relatively flexible floors, about 200m away. Vibration was felt particularly at the upper levels.

(3) The adjacent supermarket, against which we were piling to within 3m. It was necessary to change the pile type within 12m of this building to a smaller diameter driven pile with steel permanent lining tube. Once again we used the vibration monitoring equipment to enable us to find a reasonable driving technique. As luck would have it the 'wines and spirits' counter was along the wall adjacent to our site. Using the vibration monitoring equipment we were able to observe that the permissible vibration outlined in *DIN 4150* coincided consistently and reliably with a barely perceivable excitement of the Advocaat bottles, which increased noticeably with increasing vibration levels.

Asking the RE to stare at rows of Advocaat bottles for hours on end during piling operations is admittedly an unusual request. However, it enabled him to meet several 'interesting people' and he is now well practiced in Zen and Kendo:- the 'Way of the Bottles'.

Not all methods of measurement require gauges and dials.

It should be explained at this point that we were interpreting vibration readings in accordance with *DIN 4150* which contains a fairly arbitrary and very global set of figures for different building types.

However, the main object of using this equipment was twofold:

Firstly, to record the effects of adjusting the driving technique in order to minimize vibration, whilst still achieving reasonable driving progress.

Secondly, as a public relations exercise so that all the 'interested' parties could see that we were taking the problem seriously.

For some reason most people seem peculiarly reassured by the sight of someone with a box full of dials, aerials, headphones, etc: the technological witch-doctor. but still, the techniques proved valuable and successful on both counts.

Services

Air conditioning

The underfloor air conditioning system, using the raised floor as a supply air plenum, was designed for an adaptable open plan office which can respond to the rearrangement of rooms and internal heat sources without major modifications.

A program was developed to analyze the room thermal dynamics, taking into account the large thermal capacity of the concrete areas presented to the space by the structural ribs. As the heat gain to the office space reaches a peak during the day the resultant temperature swing is limited by heat transfer to the cooler concrete which reduces the capacity required from

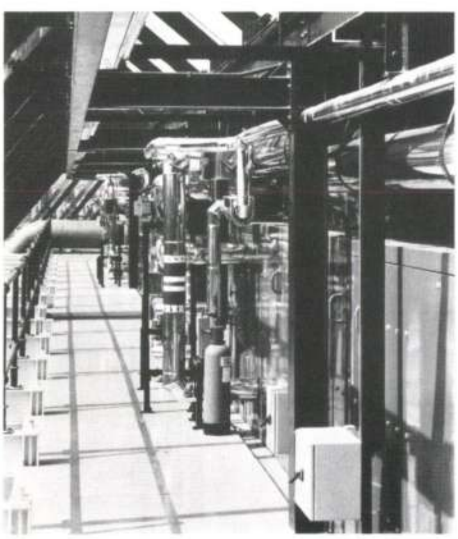
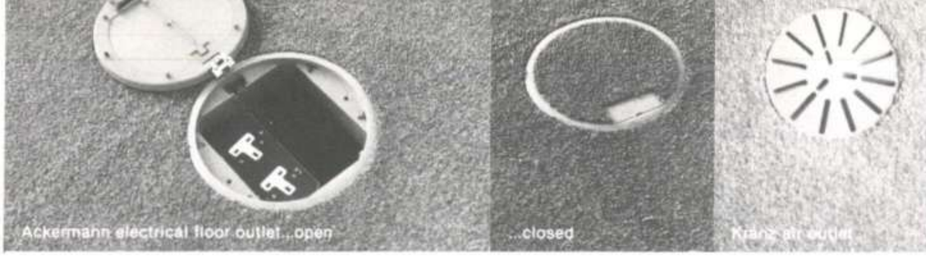


Fig. 10
Plantroom at roof level


Ackermann electrical floor outlet...open ...closed Krantz air outlet

the cooling system. This heat is later rejected back into the space as the temperature falls at night and in the early morning. The computer program predicted that a constant supply air temperature of 18.5°C with a constant supply air volume of six changes in the worst zone would maintain a maximum dry resultant temperature of 22°C at 1.5m above floor level. A maximum temperature in the return air duct of 28°C was anticipated.

Subsequent monitoring of the building's environment has proved the accuracy of these predictions and confirmed that no room terminal controls are required to cater for the repositioning of the outlets to provide a new load pattern. A sophisticated control system is, however, provided to the central air handling plant to utilize outside air and evaporative cooling whenever possible.

The air handling plant for the offices is located at roof level and is divided into four systems, each serving approximately one quarter of the total office requirements. The main insulated supply ducts drop down in the space between the two glass skins of the southern elevations and connect to the floor void plenums at each level.

Air is supplied to the office space through Krantz twist air outlets which can be shut down if they are not required or relocated when the offices are rearranged.

Air is extracted through ducts integrated with the luminaires and passed to header ducts within the raised floor above, which in turn connect to the main air risers in the service cores.

Extract air is recirculated or exhausted in varying proportions at the dictate of the control system. The recirculated air is either mixed directly with outside air or bypasses the evaporative cooler to achieve the required air condition supply.

Outside air is normally introduced into the air handling units through louvres in the roof plantroom walls but in the winter when solar gains and office heat losses warm the air in the double glazed void, the outside air is taken from this space to reduce the air handling plant loads. In the summer when warm air in the double glazed void would increase heat gains to the office space, the void can be ventilated by opening louvres in the plantroom wall to encourage air movement by 'stack effect'. These louvres also open automatically to ventilate the cavity if smoke is detected.

Heat loss at the perimeter is offset by finned convector radiators fed from the compensate temperature heating system and controlled by thermostatic valves. The perimeter areas are protected from excessive heat gains by motorized venetian blinds activated by solar radiation: The louvre blades are perforated for about 20% of their area and so appear transparent rather than opaque and allow views to the outside without a major heat gain problem. The blinds are lowered at night and during weekends in the winter months to minimize heat loss from the office spaces.

As a guide to energy use the building has an office area of 8,250m², a boiler output of 700kW, a chiller capacity in the region of 400kW and maximum electrical demand of 500kVA.

Electrical services

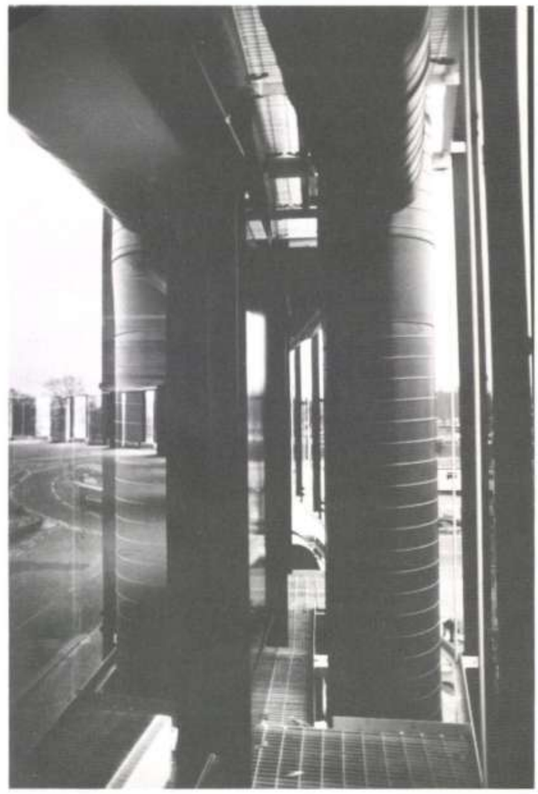
The continuous air handling luminaires located between the ceiling ribs in office areas were specially designed for the building and developed with Thorn EMI. They provide an average 600 lux at working plane and also evenly light the whole of the ribbed soffit.

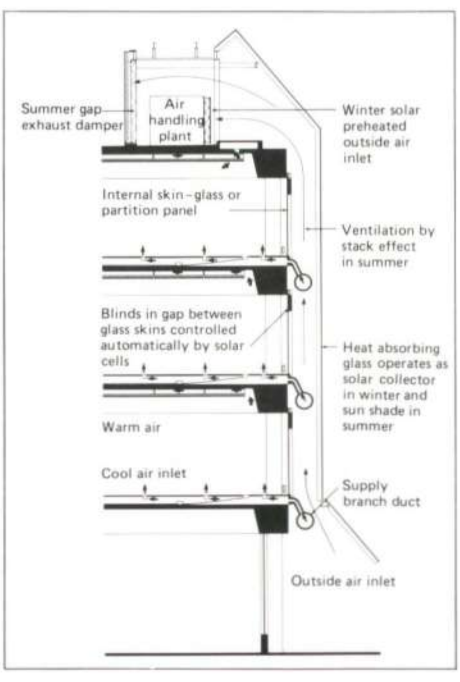
The luminaires have continuous fluorescent tubes with white cross blade louvres below a continuous extract duct which is triangular in section. On both side faces of the duct are finely perforated metal panels with absorbent acoustic backing to limit the amount of sound which is reflected back into the office space. The amount of air extracted from the space can be varied along the full length of the duct by opening or closing regularly spaced outlets. Segregated mains with through wiring facilities are provided as well as 300mm/8W emergency lamps, inverters and control gear fed from a central battery. The luminaires are block switched from the service cores to ensure that the ceiling is evenly lit, allowance for future subswitching is also included at the client's request.

The main office pedestrian circulation routes are lit by continuous suspended tubelights which follow the curve of the building and illuminate the concrete soffit. These fittings were also specially designed and include emergency lights and low voltage dichroic spots which highlight the concrete columns.

The main electrical power telephone and VDU services which rise in the stair cores distribute horizontally within the raised floor void to a grid of fixed junction boxes. From these boxes flexible cable connections are made to multi-service Ackermann floor outlets which can be rearranged to suit new furniture layouts when alterations are made.

This ability to move the electrical and air supply outlets proved to be a considerable advantage during the fitting up period when office layouts were amended right up to the time the building was occupied.





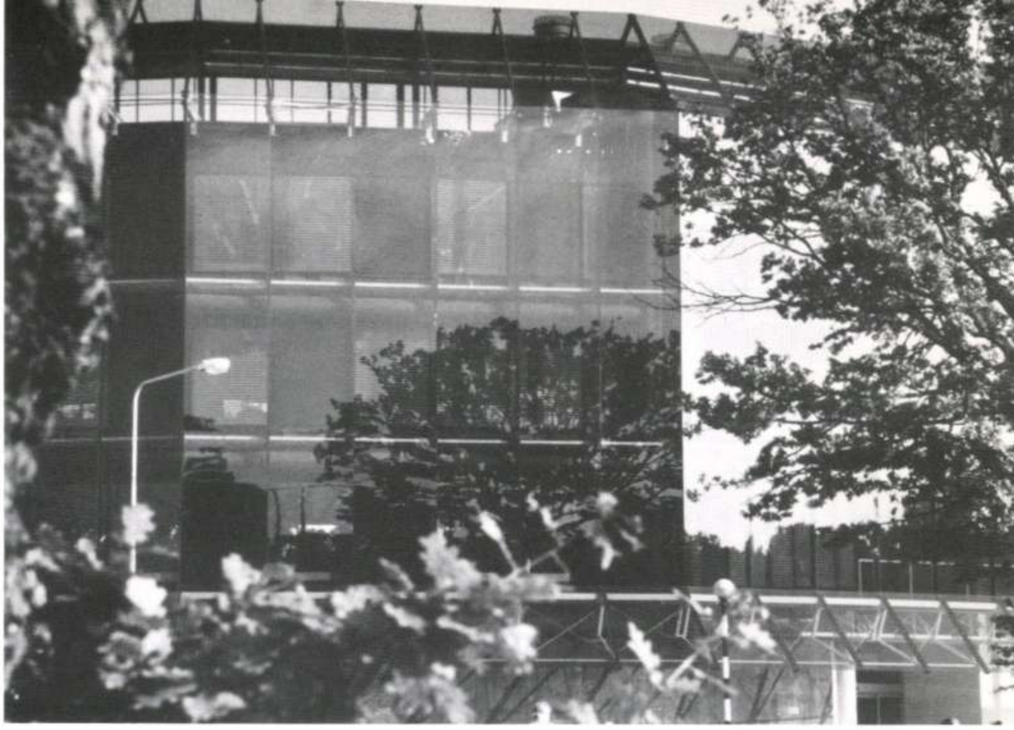



Costs

The building provided a gross area of 9,500m^2 of which 8,250m^2 was office space completed to good quality property developers, standards with raised floors and carpet throughout.

The total cost of the building was £7m. for which we were directly commissioned by Leslie & Godwin. An additional £2.5m. was spent on fitting up the interior. This included the fitting up of the restaurant, kitchen, bar, computer room and offices as well as a complete range of new furniture for the whole building.

Start on site was delayed by two months but apart from this, the building was completed to programme and was within the budget.



Reflections in the bronze glass outer skin and below: the main office entrance

Programme

Arup Associates
commissioned by Leslie & Godwin
September 1978

Outline Proposals
approved by Leslie & Godwin
December 1978

Outline Planning Permission
January 1980

Imperial Group Pension Trust Ltd.
became client
March 1980

Revised scheme design
approved by Imperial
June 1980

Detailed planning permission
November 1980

Laing Management Contracting Ltd.
appointed
June 1981

Start on site
November 1981

Building hand-over
February 1983

Interior design and
fitting out contract completed
August 1983

Credits

Client:
Imperial Group Pension Trust Ltd.

Designed by:
Arup Associates

Main contractor:
Laing Management Contracting Ltd.

Photos:
Peter Cook
Crispin Boyle
Arup Associates

Ronald Stewart Jenkins: engineer and mathematician

Ronald Hobbs

This talk was given to the History Study Group of the Institution of Structural Engineers at Imperial College on 16 December 1982.

Introduction

Perhaps the best example I can give of Ronald's approach to his subject is the day he came to the office with his completely general definition of n-dimensional strain.

Most engineers, for obvious reasons, begin by making a maximum number of approximations or assumptions; Ronald always preferred to approach problems as generally as possible and build in the necessary assumptions which flow from real life as late as possible.

This was the mathematician showing through.

I should also like to quote from Ove Arup's introduction to RSJ's book *The Theory and Design of Cylindrical Shell Structures:*

'It would, however, not be advisable – or even safe – to employ approximate methods in all cases. They ought to be employed only by designers experienced in the application of the complete theory.'

Ronald, however, was essentially an engineer, and his meticulous attention to engineering detail – where the reinforcing bars actually went in the concrete – was a by-word to the few people who had worked closely with him.

I first met RSJ in late 1948 – a client had recommended to Ove that he take me on, and I suppose he felt that if I saw all the partners one would come up with a good reason why they shouldn't. Anyway, I joined, and after a couple of months, started work with Ronald on various buildings in the Festival of Britain.

Statically indeterminate structures

At that time my knowledge of the solution of statically indeterminate structures rested on a confusion of Hardy Cross and strain energy.

Ronald very quickly introduced me to matrices, via Aitken's little book and his own adaptation of influence coefficients using matrices. He managed to condense the whole subject of statically indeterminate structures to three very short lines – that is my memory: John Henderson says half a page! This, padded out a bit, was given as a paper to the Euler Society in 1953, after being refused by the Institution of Civil Engineers as being either (a) too easy, or (b) too complex. The complete paper is, I believe, only published in the Ronald Jenkins Memorial Issue of *The Arup Journal*.

It had long been clear that Ronald had considerable ability, but it was not until fire-watching during the War that he ran into matrices and realized what a powerful tool they could be, coupled with Ostenfeldt's influence coefficients, to which, in the original Danish, he had been introduced by Ove Arup some time before – they were both working for J.L. Kier at the time.

John Henderson will no doubt remind us graphically how he just happened to introduce matrices to Ronald Jenkins one night; an introduction which I feel sure that John will agree has been amply repaid, not to mention the teaching of later generations of Imperial College students.

The whole concept of statically indeterminate structures set out by Jenkins had an immediate appeal because of its undoubted elegance. Ronald attacked most problems as elegantly as possible; in solving a statically indeterminate framework he would spend much time in choosing the necessary cuts and releases in order to make the resulting equations as well-conditioned as possible.

All this is perhaps summed up in a well-loved and much polished summary in Chapter 8 of *The Theory and Design of Cylindrical Shell Structures:*

'When matrices are used we obtain the symmetric form as a geometrical consequence, without appeal to the concept ion of work, which is merely the name of a scalar invariant associated with contragredient sets'.

I am sure that today's very young students of 'New Mathematics' would appreciate that.

One of the tests of Ronald's concepts came immediately after the War with the introduction of prestressing to statically indeterminate structures. The calculation of the so-called parasitic stresses was taken in its stride by this concept. It also naturally dealt with forces created by temperature and shrinkage.

Nowadays we all, or almost all, use computers, large or little, for all calculations. When I first met Ronald he was using a hand-operated Facit for the solution of 8 × 8 and larger simultaneous equations, using Fox's method for inverting a matrix. Computers chew up equations and spit out the answers without tasting them at all – but maybe that's just nostalgia for the heady post-War years.

He was, however, at a very early time acutely aware of what computers could do for us. His contribution to the 'Dome of Discovery' paper at the Civils in 1952 brought from one of the authors a question – What are digital computers? – but it must be remembered that it wasn't until one year later that IBM entered the computer field! Computers have taken the drudgery from arithmetic calculations, but also possibly have taken some of the joy and pleasure from analysis. I also think that it was a great pity that RSJ became seriously ill before computers had caught up with him!

Shell structures

The other great interest in Ronald's professional life was the 'third dimension'. Many engineers and unfortunately quite a few architects are two-dimensional men, and it is a mark of the great engineer or architect, his understanding and use of the third dimension. To me at least, Ronald's understanding of the third dimension was virtually complete and quite intuitive. Outwardly, this is perhaps best shown in his interest in, and work on, shell structures.

By the time I met him, RSJ had already published *Cylindrical Shell Structures* and was well on the way to an enduring and increasing interest in the mathematics of engineering; towards the end of his career this was taking him into esoteric and rarefied atmospheres where few could follow – I, for one, was only happy at ground level.

Two papers late in his life and published in the Memorial Issue of *The Arup Journal* deal with such subjects: *Towards a Variational Method for the Static Equilibrium of Curved Bodies and Shells* and *Membrane Theory in General Co-ordinates by Matrix-Tensor Methods.*

I am not aware that this work has led anywhere – perhaps the computer which does not admire elegance has made them unnecessary – but I am sure that if Ronald had been able to develop them, our understanding of complex three-dimensional shell structures, thick or thin, would have been greatly increased.

Ronald, of course, was not one of this world's natural, easy, communicators. Anyone reading – if 'reading' is the right word – *Cylindrical Shell Structures* can see that, but by the time you understood him and what he was driving at, it stuck for ever.

You would also appreciate the mathematical elegance of all his work.

One example is an equation in the book on cylindrical shell structures. In one line a multiplier in a matrix equation is given as $\frac{t^2}{2\sqrt{3}}$. A little later the same equation begins $\frac{2\sqrt{3}}{t^2}$. On being asked by one eminent engineer to explain, Ronald was puzzled; he was, after all, only solving a set of differential equations, and reversing that particular multiplier merely changed the value of the arbitrary constants. So why the question?

Jenkins the man

Ronald as a man was difficult to know at first, essentially shy, which was sometimes mistaken as aloofness.

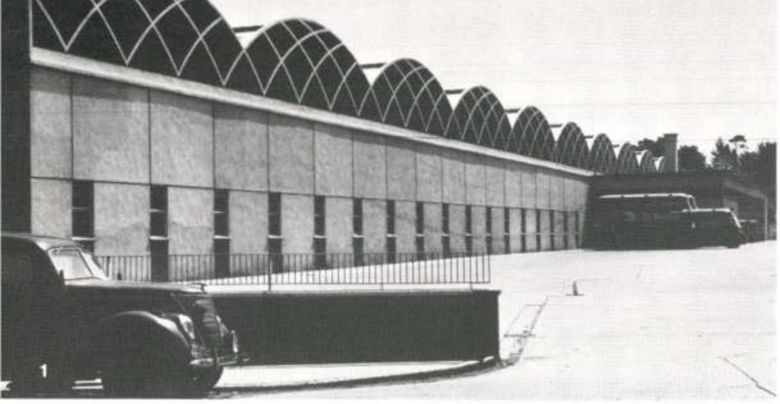
An example of this, and one of my favourite memories of Ronald, is the time two now eminent services engineers came to visit him. I found them wandering around and sat them in his office to wait. I went away to do some work, came back an hour later: they were still there, no sign of Ronald, so I said 'Well, what happened?'

'Well', said the visitors, 'he came in, sat at his desk and he started doing some work.'

Now, it was nearly impossible to interrupt Ronald when he was actually doing some calculations. 'And,' they said 'a little later he got up, and he put on his coat and he went out.' I asked him the next morning, and he said 'Oh dear. I'd forgotten. I thought they were the auditors!' We had a habit in those days of lending out his office to the auditors once a year so they could check whether we were making a profit or not.

However, through his work he formed several unusual and lasting friendships. For example, with the contractor engineer, the late B.H. Broadbent, and the architect Peter Smithson – two entirely different people but who both intuitively understood that Ronald's appreciation of the part structures play in buildings went far deeper than merely his mathematical ability to solve complex problems. To me, nowhere was this more demonstrated than in Hunstanton School, a simple project – as simple as the Smithsons could afford to make it – but where in the course of its solution Jack Zunz and I learned virtually everything there was to know about the plastic theory at that date – and still the building stands up!

Looking back over 35 years, and certainly on reading RSJ's published works, one might be excused for thinking that here was a theoretical engineer bemused by mathematics for mathematics' sake. This



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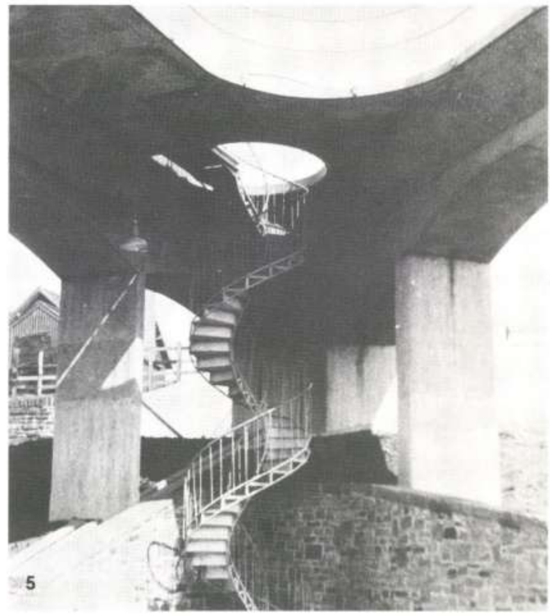

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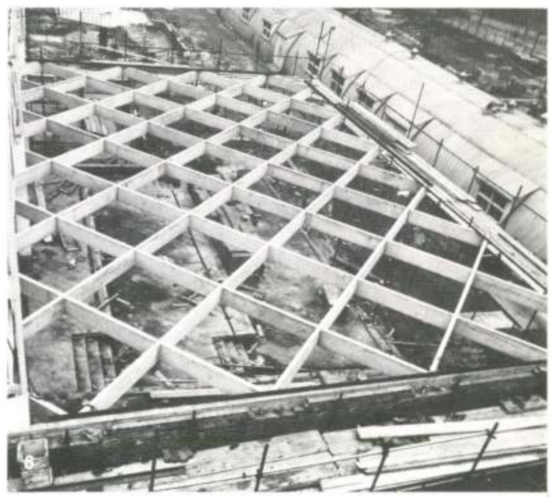

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may be somewhat true of his last few years, but in his career generally it would be a parody of the true worth of RSJ. He was, first and foremost, a practising engineer in small things and large; he was devoted to detail. John Henderson's tribute to RSJ in the Memorial Issue of *The Arup Journal* contains the following:

'As a small example, his design for the concrete pump hopper loading gantry at Eastbury Park (1942) was a model of engineering economy and grace. It was formed from a frame of telegraph poles supporting some old steel beams from the yard, these in turn carrying the roadway leading to the hopper. The erection was done speedily by a few men under an able ganger with no mechanical plant. Everyone knew it would be right for the job and be trouble-free (barring some event totally outside the terms of reference), since it bore the RSJ thumb print. Similarly, any contract estimate he made had the same distinctive character, and a site agent was fortunate indeed to have such a document as his price guide.'

His drawings on the wartime project Heysham Jetty were for long regarded in the firm as a masterpiece of engineering detailing and draughtsmanship. Ronald didn't do anything he would not do expertly, whether it was mathematics, engineering, gardening, climbing or tennis.

Things discovered, or rediscovered, by RSJ now look obvious – a mark of true genius!

It would not be right to leave a discussion on RSJ's work without some visible reminder that real buildings flowed from his hand.

Unfortunately, as Sir Ove said at our last meeting, much of the pre-War, War and post-War work which he and later RSJ were associated is left unrecorded, partly because it has been lost, and partly because the 35mm camera and colour film were not such common features then as they are today.

Anyway, from 1946 onwards, the start of Ove Arup & Partners – RSJ was, of course, a founding partner – some photographic records of his work are available.

Starting in Dublin where Ove set up an office in 1946 to do some work with Michael

Scott, Fig. 1 shows the shell roofs at Donnybrook bus garage. It was during this time that another possibly apocryphal story of Ronald circulates. He had by this time written his book which, as those of you who know it will remember, is rather sparse on

Fig. 1
Donnybrook Bus Garage
(Photo: Deegan-Photo Ltd.)

Fig. 2
Dublin Bus Station
(Photo: *copyright Architectural Review*)

Fig. 3
Brynmawr Rubber Factory

Fig. 4
Interior of Brynmawr Factory

Fig. 5
Steel spiral access stair
at Brynmawr Factory

Fig. 6
Festival of Britain restaurant roof

Fig. 7
Kidbrooke Comprehensive School
assembly hall (Photo: John Maltby)

Fig. 8
Bank of England Printing Works
(Photo: John Holden)

Fig. 9
Prestressing arrangements
for Bank of England Printing Works

Fig. 10
Main production hall
of Bank of England Printing Works
(Photo: Archie Handford)

words and rather full of equations, and apparently at a party in Michael Scott's office one night, it was getting very late, and Michael got the book which Ronald had given him, put it in front of the pianist and said 'Now, play *that!*'

Fig. 2 shows what was probably one of the first shell roofs calculated by Ronald. It doesn't give a very good picture of the shells here, but those 3 inch wavy shells do cantilever about 20ft. This is the bus station at Dublin which stood like that in all its glory for some time while successive Irish governments paid us abandoned work fees to keep the office alive whilst they made up their mind what they wanted to do with it.

Then we come to perhaps the largest exposition of shell concrete in this country; the Brynmawr Works for the Earl of Verulam of Enfield Cables, with its nine 90ft. square domes and a number of cylindrical shells of different types around it. This is shown in Fig. 3.

The inside of the dome shells is shown in Fig. 4.

These shells were designed in 1946 before prestressed concrete really got going in this country, and the edge beams are in reinforced concrete. I think a few years later they would certainly have been prestressed.

Fig. 5 is a funny little staircase which went round two and a half turns and it does that simply because the Earl of Verulam who was the client had seen one like it in Switzerland, and please could he have one like that. So Ronald said 'Yes, why not?' It was rather slender, and it did move about three inches when you walked up it, but in later years Ronald went to Switzerland to see this other staircase and found that it was anchored at mid-point!

Fig. 6 shows a building on the Festival of Britain site, probably one of the first prestressed statically indeterminate structures – a diagrid roof which formed the Fairway Restaurant. I shudder to think of some of the details today, with the Freyssinet female cones stuck on the outside of the concrete, but they worked.

Fig. 7 shows the hall of Kidbrooke School which was at that time the first of the large comprehensive schools built in this country. It had 2000 students and the roof of the assembly hall was a concrete shell dome. The edge beam which you can see on the right hand side was in this case prestressed.

There is rather a nice story about this project because Ronald had finished the calculations and then suddenly decided – something he rarely did – that somebody ought to check them. And in the first line is the ratio r/R and that he had got wrong. Everything else was right. So, on being told this, he had a very good lateral thought. He rang the architect and said he couldn't possibly design a shell with the ratio r/R that the architect wanted, it had to be the one he had used in his calculations – and no architect could dispute that with Ronald!

Fig. 8 shows the Printing Works of the Bank of England. The structure of the main Printing Hall was a series of shells carried on arches. The arches were precast and stressed together using the Freyssinet system, and Fig. 9 shows a diagram of the prestressing arrangements. Fig. 10 is the inside of the construction as it was going on. There were 22 identical bays; the construction of the first one took three weeks and of the last one, two and a half days.


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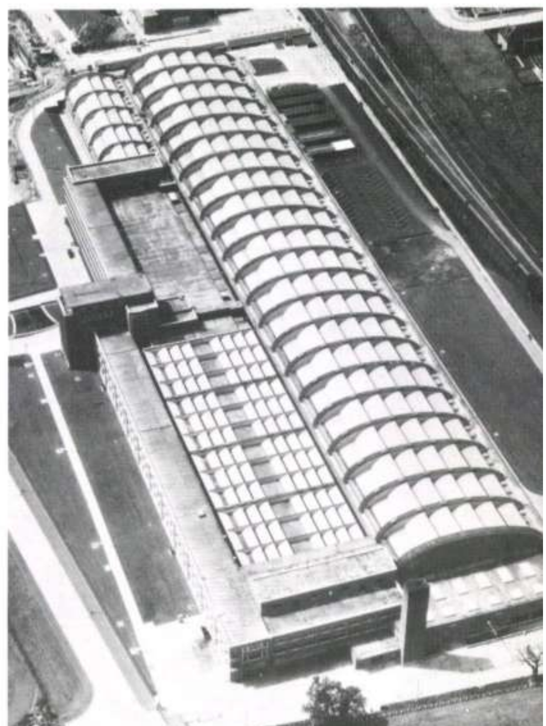
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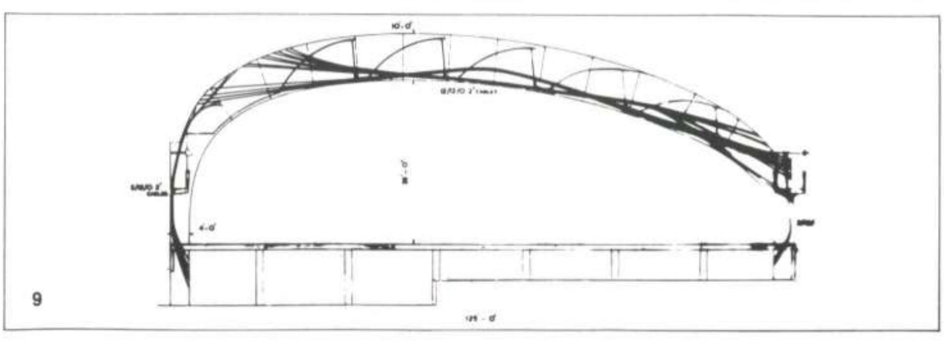
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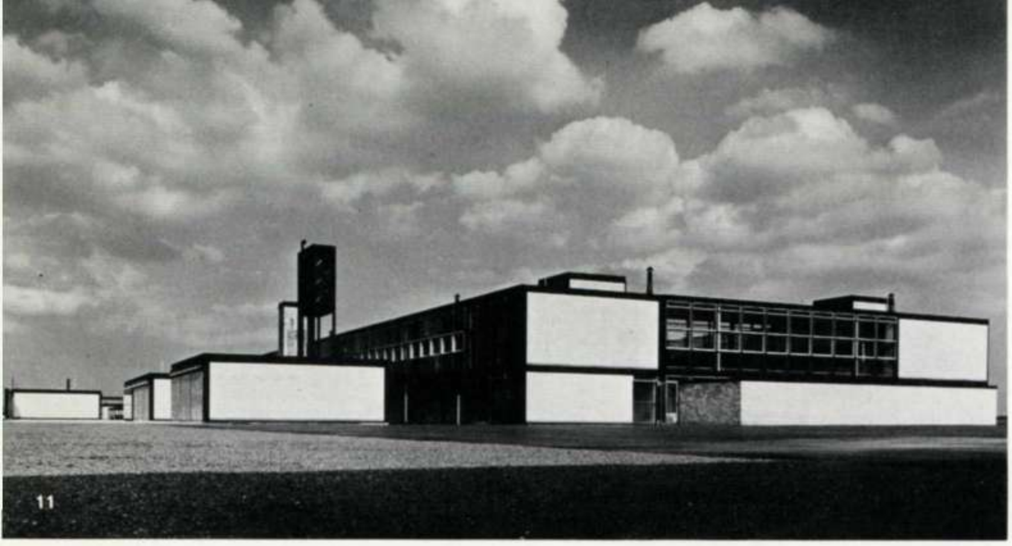


Fig. 11
Hunstanton Secondary Modern School
(Photo: *copyright Architectural Review)*

Fig. 12
Park Hill housing, Sheffield
(Photo: *copyright Architectural Review)*

Fig. 13
RAF Hangar, Abingdon
(Photo: *copyright* John Laing & Sons)

Fig. 14
C&CA, Wexham Springs
(Photo: Sydney W. Newbery)

Fig. 15
Gaydon Hangars
(Photo: John Laing & Sons)

Fig. 16
Lattice shell at workshop for
Scaffolding (GB) Ltd., Mitcham, Surrey

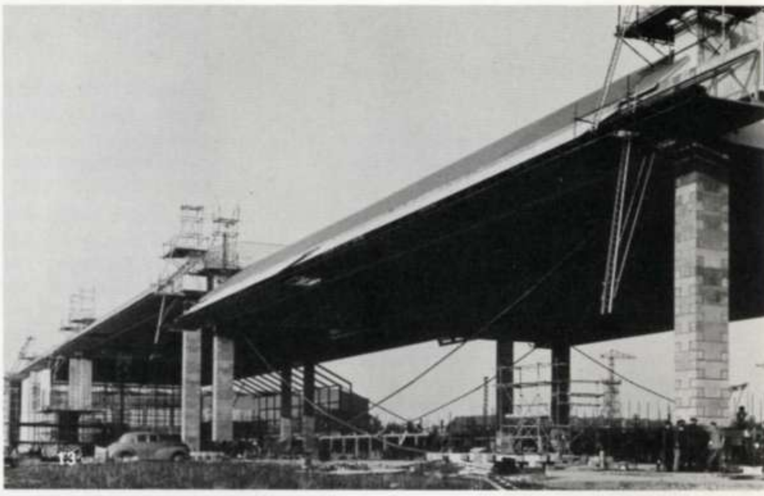


Fig. 11 is a view of Hunstanton School. It was a very simple building but the sections which the Smithsons had chosen to put in their competition design were without the benefit of engineers, and it took us a long time and a considerable appeal to plastic collapse theory to convince ourselves that *with* the benefit of engineers we could leave them as they were.

Ronald occasionally, and very occasionally, got mixed up with what the rest of us engineers would call bread and butter work, and Fig. 12 shows the Park Hill Flats at Sheffield. The reason why he did is beyond me now, but apparently there were site meetings he went to for several months and didn't say a thing. One day he was noted to be about to speak and everybody waited with bated breath. And these words came: 'I believe that is my pencil you have'.

During these years when he formed a very close relationship with B.H. Broadbent, then a director of John Laing, we designed a couple of Royal Air Force hangars by entirely different methods. Fig. 13 shows the one at Abingdon, made entirely of shell roofs. They were cast on the ground and jacked 40ft. up into the air. Whilst the edge beams were on the ground the shells stayed up quite happily as arches, so enabling them to be cast with a travelling shutter.

Fig. 14 shows a small project at Wexham Springs when Professor Morice of Southampton University, another close friend of Ronald's, was director there. An interesting thing about this job was that for a long time the shells had no waterproofing on them at all – the valleys which were the 'edge beams' were prestressed.

Very occasionally, Jack Zunz or I got Ronald to build a statically determined structure. He wasn't very keen on such structures, but Fig. 15 shows the Gaydon Hangars – a roof with a three-pinned arch.

Another development he was concerned with was a lattice shell – a device for pre-fabricating lattices of tubular steelwork, putting them up in position and then covering them with lightweight concrete. Fig. 16 shows one of these shells.

Now I come to a project which was not built. The Smithson's competition design for Coventry Cathedral was one of the projects which Ronald would have most liked to have built.

The Coventry Cathedral design was a 200ft. square shell carried on edge beams, and Figs. 17, 18 and 19 show the proposal and its relationship to the existing spire which was all that was left after the bombing of Coventry.

Another unbuilt project was a new roof for the Centre Court at Wimbledon. This would have had the same outline as the well-known court today, but all the internal columns would have moved. (We had a special sort of rain which moved uphill to get away from the drainage problems.)

The structure simply consisted of a number of columns around the outside and a grid structure, two rings, one compression ring and a tension ring filled in with lightweight roofing. This was taken as far as obtaining a tender for the now ridiculous sum of £193,000, but still it didn't go ahead.

This paper was followed by a general discussion, and some of the better recorded contributions follow.

Sir Ove Arup:

'You see, when I met him first at Kiers, I could very soon see that his intellect was quite unusual, that I hadn't met anybody in England with what was almost his Continental approach to the problem....He was very strict. He was a perfectionist. It is quite right that it was very difficult to understand what he had written....He said "I'm not *trying* to make it easier for people". He was trying to get the admiration of the people who understood him you see. He was writing for his kind of people and he didn't suffer fools gladly. Now that can both be good and bad....but he was also practical at the same time....'

Professor Peter Morice:

'I feel I have an enormous debt to Jenkins. The first time I ever came across him was soon after I'd come out of College. I was bored with what I was doing at Surrey County Council so I went back to see my professor who was Sir Alfred Pugsley in Bristol and said "I don't like what I'm doing, can you find me a better job? Any recommendations?" And he said "Yes, there is a job coming up at the Cement and Concrete Association for research. Also there's this book," and he produced Ronald's book. He said "I don't really understand this, but I'm sure it is where the future lies, in structural analysis. Read that, my boy, and you'll be able to carry on for years and years and years. It is really the basis of your future work." And indeed, he was quite right. So I read the book: I didn't understand it, and it took me many years before I did. I got the job with the C & CA and happily, very soon afterwards, met Ronald and, being involved in concrete research, came across him quite a lot and became, I'm happy to say, very friendly with him.

On the paper you mentioned, incidentally, I don't know whether it is possible – perhaps John (Henderson) can help here – but I understand that the paper was submitted to the Institution of Civil Engineers and Pippard was one of the assessors and said this was nonsense and far too difficult, and nobody would be able to read this sort of thing, so the paper was left, and I still possess a copy of it.'

John Henderson

'It was partly my fault that it wasn't published. What Pippard said was that people won't understand it. He didn't say it was nonsense. He said that if you aided and abetted to make it easier to understand then he would publish it....but Jenkins said "I don't want it messed about with", which of course was quite right.

Professor Peter Morice

'I was just going to go on and say that I would like it "recorded" so to speak; that people know about the strong connections between Ronald and Yves Guyon because Yves, of course, was the great analyst of France and Ronald was the great analyst of Britain and they really got on extremely well together. They talked the same language, they were extraordinarily good friends, and they both, I think, fed off each other in a way and their friendship lasted a very long time until the death of both of them....The other thing I would like to record myself, is the responsibility of Ronald for my now state of inebriation since he really introduced me to good wines – good wines and opera.'

Derek Sugden

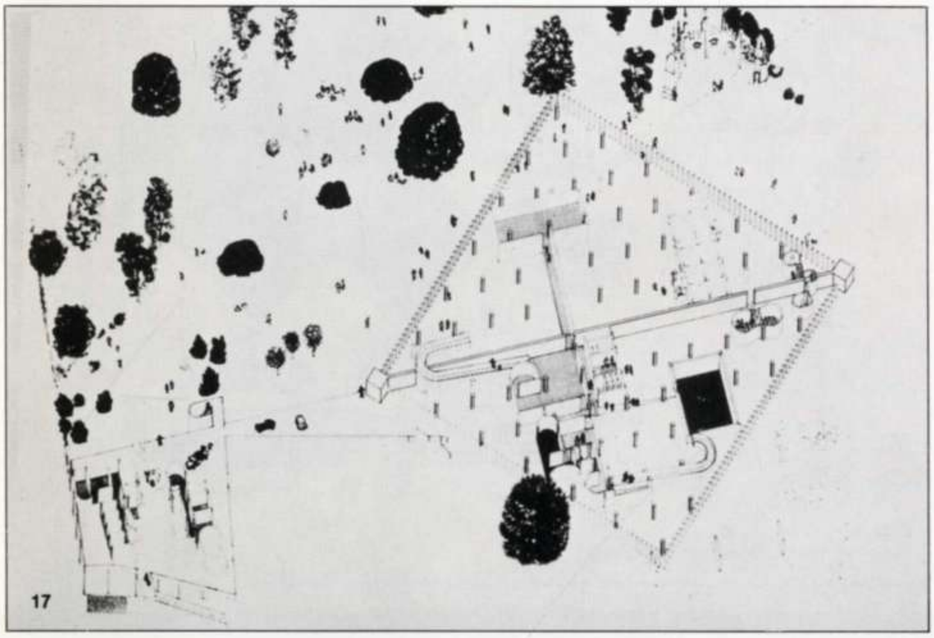
'I'd like to illustrate one or two facets of Ronald's character.

Ronald asked me at my interview what I knew about matrices and I vaguely wondered what mattresses had to do with structural engineering! But I managed somehow to get over that, and we went on to talk about real things like music.

Although I never moved in the rarified air of the analyst which surrounded Ronald, I was involved with him on one or two jobs. On Corsets Silhouette where we were rebuilding some H.P. shells designed by others, I received one of the most valuable lessons of my professional life. When rushing in to his office to tell him that he must answer "this important letter" immediately, he advised me to put it aside for a week. The lesson went on – "Put it aside for another week", he added, "then you will discover that in 99 cases out of 100 there is no need to do anything." I soon discovered that this 'Kutusov' approach was very successful, and it became an important part of my own life style.

He was the first man I met in Arups who was actually listening to Britten's operas in the '50s. He really was a man of many parts.., especially wine...and Dry Martinis. I was really a Gin man until I met Ronald and he introduced me to the delights of Dry Martinis.

Several other people contributed to the discussion including Mrs. Betty Jenkins, who described Ronald making a paper model of the Brynmawr staircase on the kitchen table.



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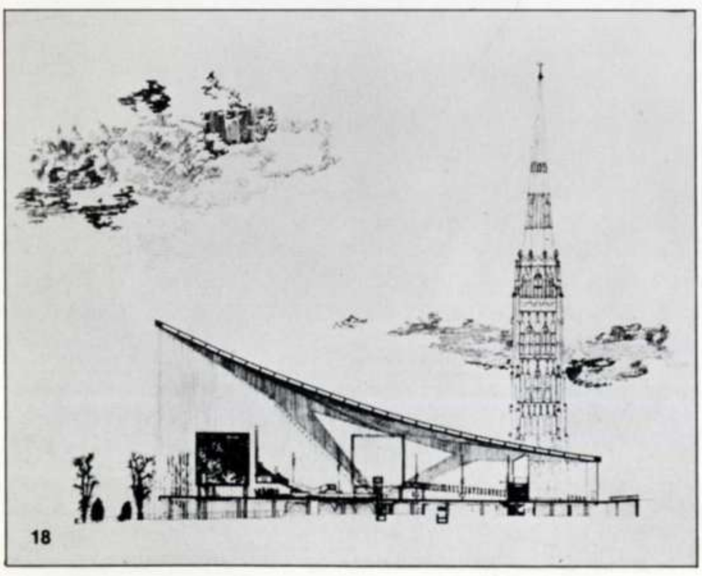

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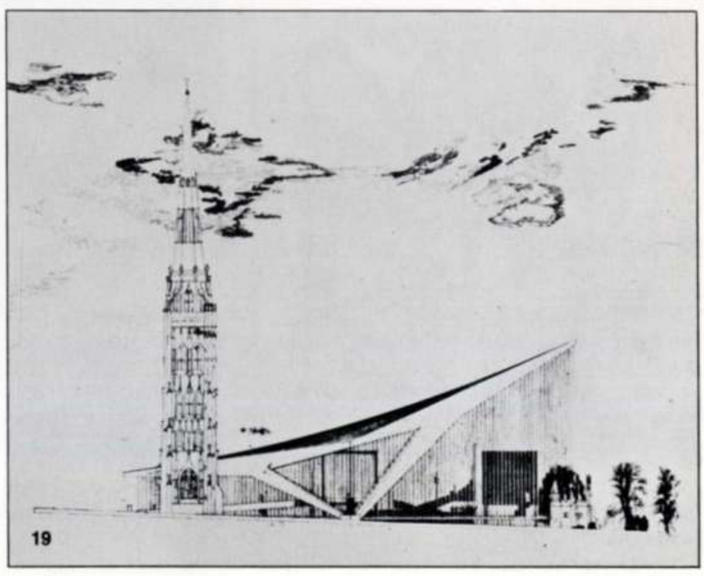

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Figs. 17-19
Competition entry
by Alison & Peter Smithson
for the rebuilding of
Coventry Cathedral

The Merlin Hotel, Perth, Western Australia

Architects: John Andrews

Keith Pollock

The Merlin complex comprises a 400 bed hotel 8,000m² of office accommodation, a retail shopping arcade and parking for 1,000 cars in two basement levels with provision for two later tower blocks.

The challenge to the structural engineer was to find economic solutions to elements including the 65m long atrium roof, the 60,000m² car park and podium deck, the 26m clear span concrete deck for the ballroom roof, the interbridge links for the accommodation levels and the intricate vaulted porte-cochères.

Ove Arup & Partners were commissioned as structural consultants for the John Andrews-designed Merlin Hotel Development in March 1981.

The $65m. development is situated on approximately 3.5ha of riverside land at the eastern entrance to Perth City.

The development has been undertaken by Withernsea Pty Ltd., a joint venture company equally owned by Diamond Hill Pty. Ltd., and Multiplex Constructions Pty. Ltd., who also constructed the project.

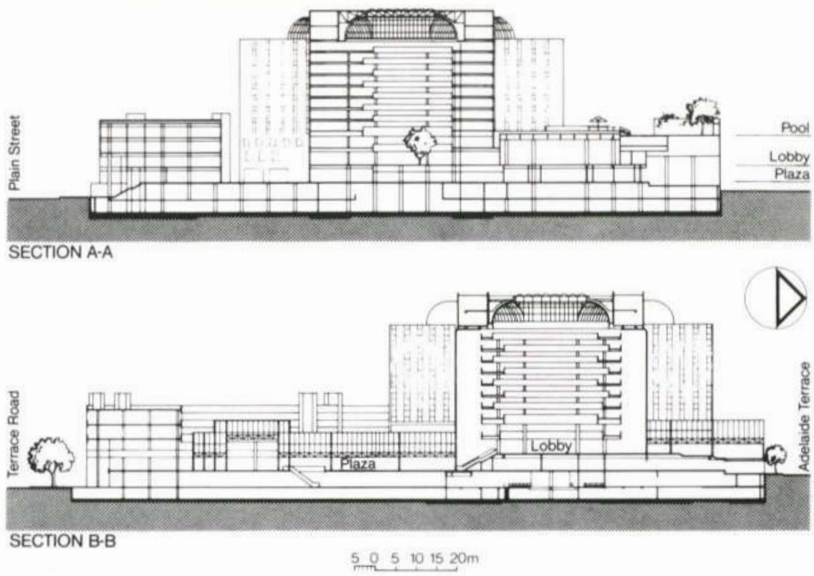
The building comprises 3 main elements. The hotel, the shops and offices and the car park.

After a forward siteworks contract, construction proper was commenced in December 1982 and completed some 18 months later in July 1984. It is significant that this short construction time also included complete fit-out of the hotel and ancillary facilities.

We were involved in all the structural elements of the building. These included the siteworks, foundations, structural frame, precast and brick facades, the atrium roof and external canopies.

The site is adjacent to the Swan River, directly behind a grassed public open space. Natural ground level varied from R.L. 1.70 on the river side (south) of the site to R.L. 4.9 on the north boundary.

Water table related almost directly to the river with some small variation above and below R.L. 1.00.



Figs. 2-3
Section through building

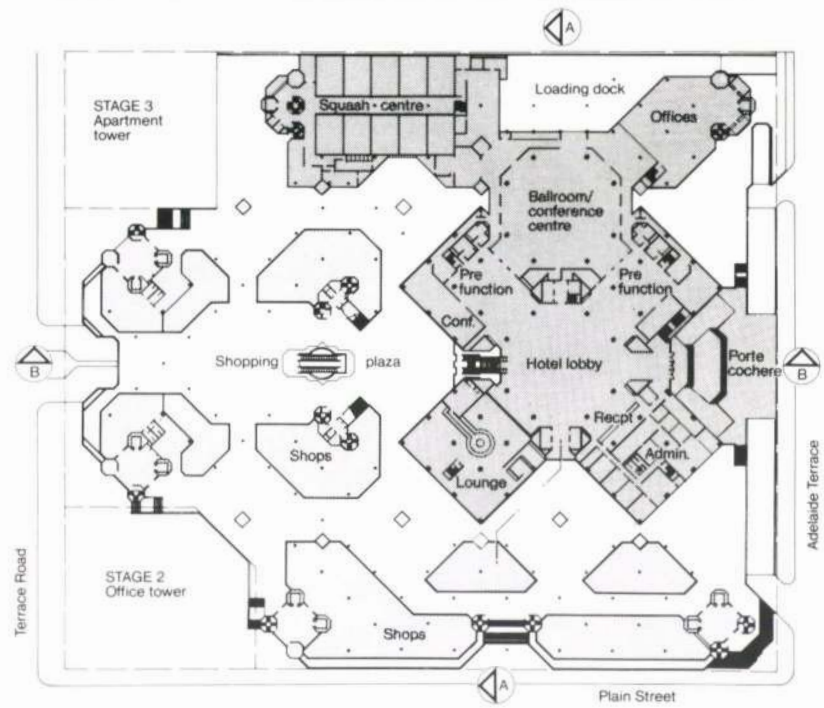


Fig. 4
Plan of Plaza/Hotel lobby levels

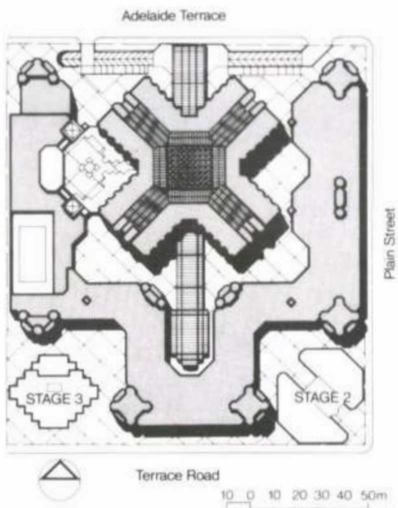


Fig. 1
Site plan

Parking for 1,000 cars is accommodated over two basement levels covering the total area of the site. The lower basement, accessed through the car park by ramps from the southern entry, is at R.L. – 1.70 with an upper basement level at R.L. 1.30.

Site investigations were carried out to enable assessment of suitable foundation systems for the hotel tower, the podium structures and also the future tower blocks to be constructed in the south west and south east corners of the site. Additional exploratory excavations were also carried out in order to assess the ability to control the possible water flow during foundation construction to the development.

The forward earthworks contract included construction of a 650m long diaphragm wall around the perimeter of the site followed by bulk excavation to foundation level. The diaphragm walls are 500mm thick and extend from the under side of level 2 car park at R.L. – 1.2 down to toe level, generally at – 5.9, to extend through the upper sand stratum into clay. The walls were tied with a single line of alluvial anchors at R.L. 0.00.

Due to the variability of the soils and water table level encountered during the geotechnical investigation, foundations were selected along with recommendations of improvement procedures where unsatisfactory ground may be encountered.

The 13 storey hotel tower to the north of the site is founded on a 1.5m thick raft with a ground bearing pressure of 150 kPa. The upper levels of the hotel utilize load-bearing brickwork. This strongly influenced the choice of a raft footing due to both total and differential settlements being less than for pad footings. The raft construction also had the benefit of creating a watertight platform early in the programme to allow the start of the slipformed hotel lift and service core walls.

The raft was constructed in two separate 24-hour concrete pours of approximately 2500m^3 each, and used a 50/50 blast furnace slag/type A cement mix.

The remainder of the structure, which is concrete framed to a maximum level 7, is founded on profiled pad footings poured integrally with the basement slab.

Various forms of dewatering were required across the site. Generally, dewatering spears were used in the north sandy strata and sumps, wellpoints and drains in the clay to the south. The slabs interconnecting the pad footings were designed for uplift pressures which were controlled by the inclusion of a grid of pressure relief tubes cast into the basement.

The car parking floor structure is a reinforced concrete flat slab with drop panels on a 9.0m column grid. This simple low cost system proved successful and permitted repeated use of formwork over a very large area.

The 400 bed hotel is entered from the north through a porte-cochère directly into the central lobby. The interior area is a cruciform plan, with mini atriums that curve around each corner as a group of bedrooms. Each atrium has interconnecting bridges in a spiral arrangement throughout the 10 storey space. The hotel also contains a ballroom, full tennis court, a swimming pool and 10 restaurants.

The hotel typical floor structures occur from levels 7 to 13 inclusive. Two brick course (172mm) thick slabs are supported on 150mm thick loadbearing brick walls.

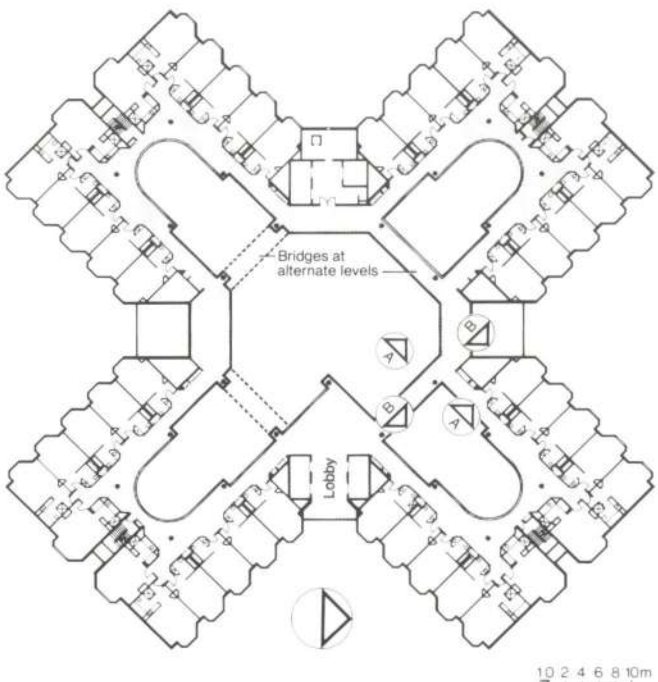


Fig. 5
Plan of typical hotel floor levels 7 to 13

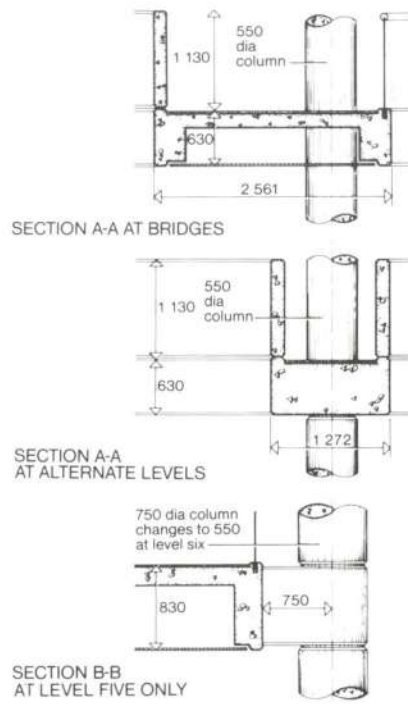
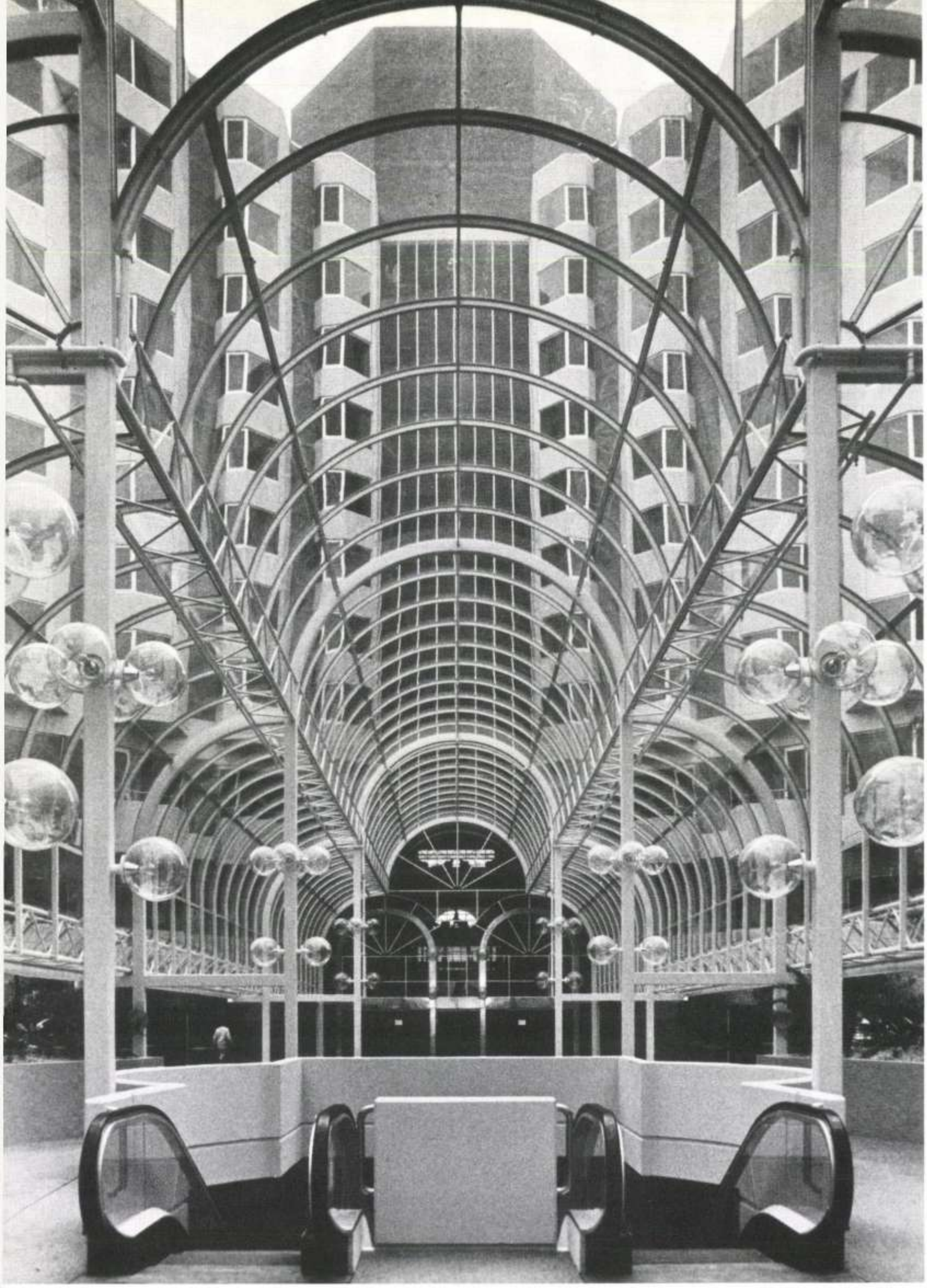


Fig. 6
Sections at bridges and levels



The brickwork has a design compressive strength of 50 MPa maximum, varying to 30 MPa at the lower floors. The tops of the brick walls have slip joints with neoprene sliding bearings at the underside of the concrete roof level to accommodate differential movement. The lift, stairs and service cores at the intersection of each of the four hotel wings are 200mm thick slipformed concrete. These walls take the majority of the lateral design forces for the building.

The level 6 hotel accommodation level is a 1.5m thick beam and slab structure transferring the hotel typical loadbearing brickwork to the 9.0m column grid of the basement carpark. The services from upper level bedrooms pass down to the underside of level 6 slab and then travel laterally through the beam structure to exit ducts.

Atrium

The atrium roof is constructed of a series of steel transparent *Lexan*-clad arches, meeting in the centre of the hotel at a square gridded space frame. All the steelwork uses standard tube or rolled sections and welded and bolted connections. The hotel roof, the front entrance canopy and the rear podium canopy are of similar construction. The larger rear canopy is a 60m long × 20m wide triple-vaulted tubular-framed structure. The subcontract for the steelwork to these roofs was approximately $1.5m.

Ballroom roof

The ballroom roof forms the external deck to the 20m long swimming pool. The roof spans 26m across an octagonal 6m high space with a grillage of beams and slab.

The beams to the ballroom roof are perforated for a depth of 500mm below slab level, in one direction, to accommodate services. A 2-stage in situ beam/*Bondek* slab construction method was devised to allow the ductwork to be fixed from the upper level prior to pouring the slab. The design also included provision of two adjustable universal column temporary props to allow delaying infill of the 4.5m square crane opening which also existed through the ballroom area.

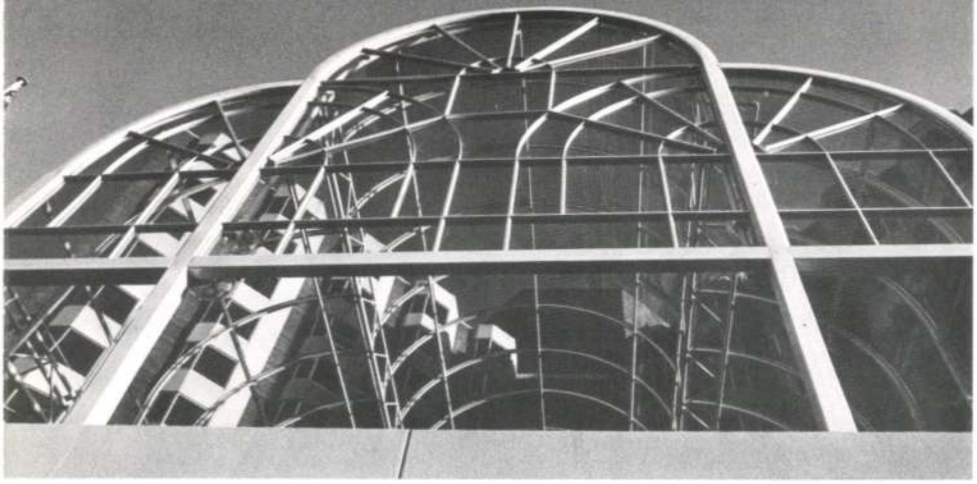
The facade of the hotel is a combination of face brick and precast concrete spandrel units. The precast units vary in thickness from 100mm to 180mm and were made on site in steel forms set up on the podium slab at level 3. Temporary shelf angles held the spandrels in position and allowed adjustment until an in situ concrete stitch was poured for final support.

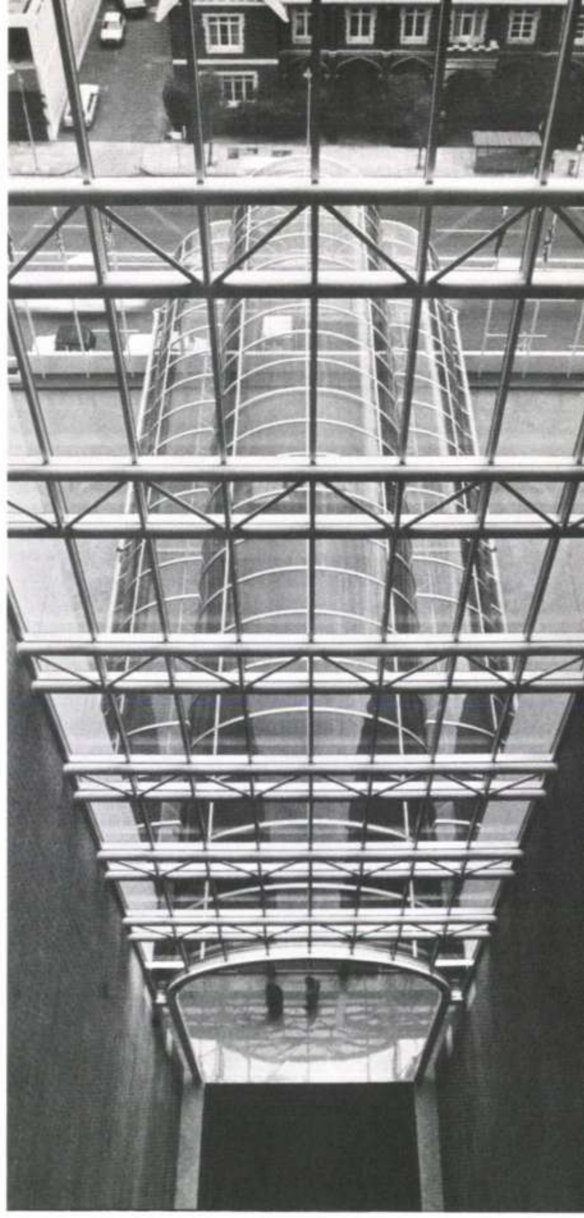
The hotel is linked by stairs and escalators to a series of external courtyards, plazas and arcades which are located at level 3. The structural slab form of the car park below this level is repeated for these areas, with adjustment to support extensive landscaping, planting and precast paving. The plaza slabs were constructed in a sequence incorporating control strips between expansion joints at 60m centres to allow for concrete shrinkage and thermal movements.

The shopping arcade has 40 retail tenancies to serve both hotel patrons and general public. Additionally, the centre incorporates a health club, squash courts, and a service station at the entrance to the car park.

Offices

The offices from level 4 to level 7 wrap around the plaza areas on three sides of the project. The 9.0m diagonal column grid extends through from the car park and supports the flat plate concrete floor slab and roof structure. The columns are set back from the facades giving mullion-free glazing and 12m open plan office spaces.





Access to the offices is through octagonally-shaped load-bearing brick stair cores located around the site. The stairs to these cores, and the hotel fire escapes, are constructed of prefabricated steel with an upturned 'U' shaped tread. The steel stairs were installed early in the programme to allow temporary access; later the treads were filled with concrete to provide a permanent (less noisy) final product.

Multiplex required the building as soon as possible, and went from the start for 'fast tracking' with design proceeding in parallel with construction. We made extensive use of our in-house computer and suite of OASYS structural computer programs to assist in producing the documents ahead of programme.

Now completed, the development has already established an identity in Perth and is proving popular with both hotel patrons and general public alike.

Credits

Architects:
John Andrews International Pty.

Client:
Withernsea Pty. Ltd.

Main contractors:
Multiplex Contractors Pty. Ltd.

Quantity surveyors:
Rider Hunt and Partners

Services consultants:
Matthew Hall Pty. Ltd.

Photos:
Harry Sowden

City site: Lovat Lane

Architects:
The Thomas Saunders Partnership

Deborah Lazarus

Introduction

The Lovat Lane Conservation Area covers the group of narrow streets to the west of the Monument, due north of Billingsgate. This is the area which until about 10 years ago housed the fish merchants'offices and stores in buildings dating back generally to the latter part of the 19th century. The history of the area goes back a good deal further, with medieval remains uncovered attributable to the town house of the abbotts of Waltham. A fine Wren church in St. Mary at Hill dates back to 1670 and is held to be one of the most interesting among those remaining.

In the early 1970s we were appointed by Compass Securities with the Thomas Saunders Partnership as architect to advise on the development of the area for offices.

The brief

The original intention was to demolish most of the existing buildings and to construct one 'mega block' which would bridge across Lovat Lane, from Botolph Lane in the west to St. Mary at Hill in the east (see Fig. 2) This was rejected, perhaps not surprisingly, by the City planners, and our work at this time consisted essentially of major refurbishment of individual units. Schemes were complicated by the requirement both to retain several listed facades, and to avoid the payment of Development Land Tax in virtually all cases. This latter restriction related in part to the proportion of new floor area which was permitted; where existing floors were retained in consequence, the available headroom was often low and did not allow the introduction of significant service zones.

Work effectively ceased in 1978 with a number of buildings remaining vacant and semi-derelict. In 1981 the development had been taken over by Guardian Royal Exchange Assurance and the concept had changed to that of the 'City Village'. The brief was to redevelop the derelict buildings as small, high quality offices and the planning consent was based on a series of ornate and complex elevations which would re-create original features from the surrounding area.

Six new buildings were required, to be constructed in four phases. The phases were to be overlapped as far as was practical, allowing for the extremely confined sites, their relative positions and the lack of access. Two buildings were constructed in each of Phases 1 & 2 (D&Q followed by R&S), with Building AB constructed under Phase 3 and M under Phase 4.

Geology and site conditions

A site investigation comprising four boreholes was commissioned in 1974. The information obtained was supplemented by two additional investigations, each comprising a borehole and various trial pits, in 1981 and 1982.

The geological succession is generally fill overlying gravel above the London Clay.

Varying conditions are encountered, however, due to the slope of the area towards the river. In particular the site at the bottom of Lovat Lane differs somewhat from those further up. The properties of the clay are slightly different and persistent bands of claystone were encountered during piling.

Structural schemes

A variety of construction materials was encountered and indeed used during the initial phase of refurbishment. The majority of the floors were timber while vertical elements were steelwork or load-bearing brickwork. Where loads were increased or new elements of vertical structure introduced, new foundations were required and underpinning of existing wall footings was necessary where basement depths were increased. Bored piles were installed in several instances, generally working in areas of very limited headroom and restricted access.

The new buildings were all designed to maximize available lettable area on infill sites. The client required all new construction to be tight to the adjoining buildings and internal columns to be used only if essential. With one exception the buildings have six storeys including a single basement and they range in size from approximately 440 – 1720m^2. We adopted a basic scheme for the Phase 1 buildings and used this, with modifications where necessary, on the subsequent phases. A reinforced concrete framed structure with coffered, two-way spanning slabs was used, with lateral stability provided by reinforced concrete walls to the cores. In general the cores were located, at least after consultation, to assist with keeping spans to a size consistent with the depth of slab selected without the need for internal columns; in one instance only, Building AB, this was not achieved; To maximize the coffered areas of slab in the irregularly shaped buildings, a 600mm waffle was chosen rather than the more common 900mm module. Storey heights were selected to suit the existing buildings and the slope of the lanes and the slab depth then tended to be determined by the required clear height and depth of false ceiling to suit air-conditioning ductwork.

The layout of the buildings was not felt to be suitable for a raft foundation and shallow pad footings would have been uneconomically large due to the eccentricity imposed by keeping all vertical loads at the perimeter of the building, and

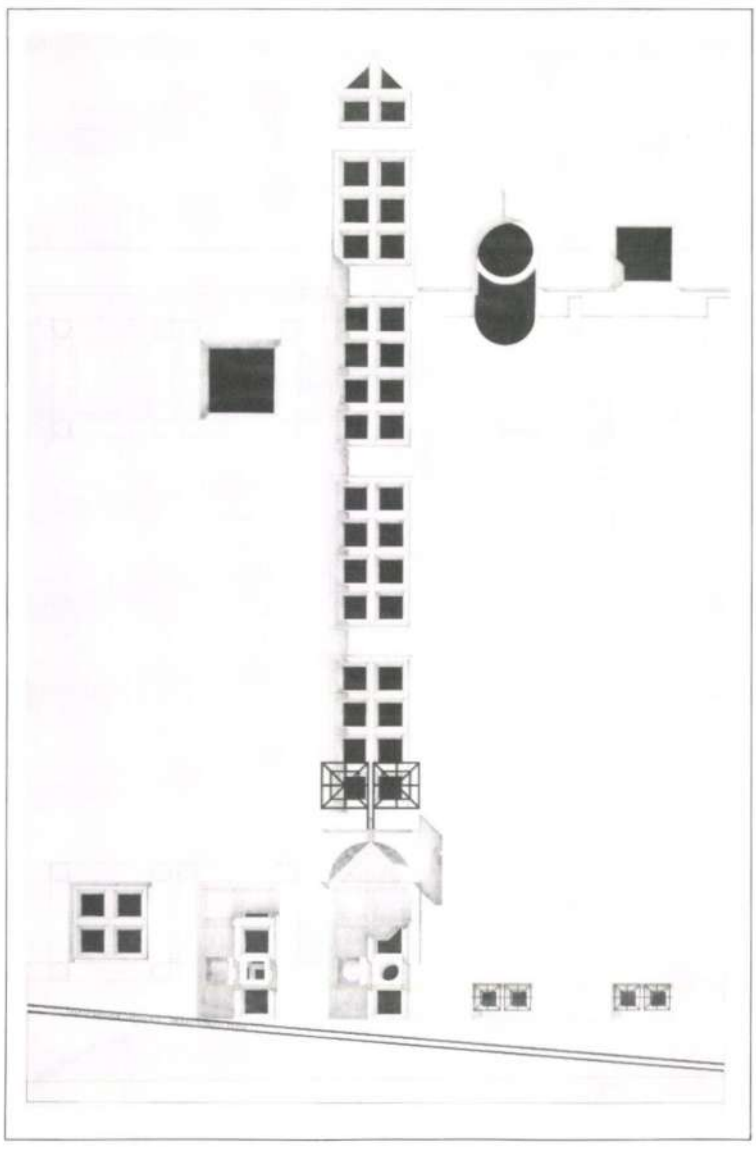


Fig. 1
Building 'R': part elevation: (Drawn by Colin Barnard)

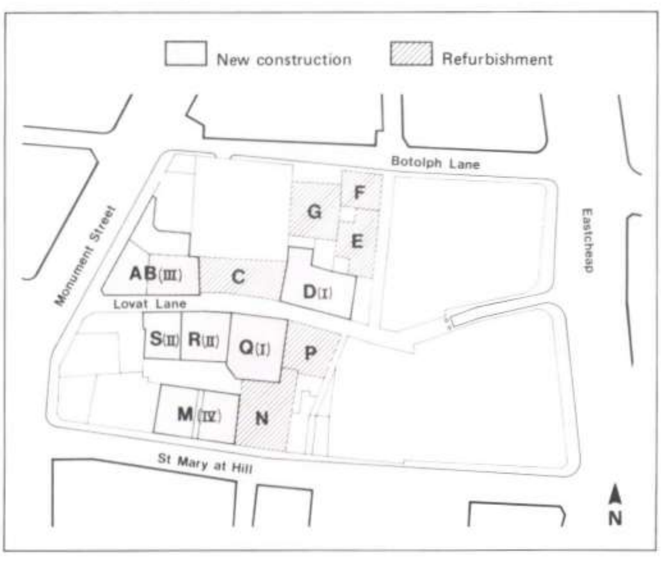


Fig. 2
Site plan

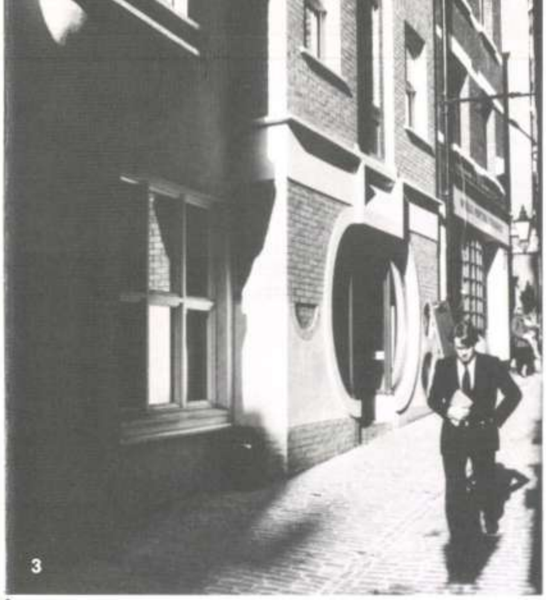


Fig. 3
View up Lovat Lane

Fig. 4
Building 'D'

Fig. 5
Building 'AB' with terracotta facade and 'onion' dome

Fig. 6
Stonemason at work on plaque, drawing attention to weathervane on Building 'AB'

hence of the site. It was decided that bored pile foundations were suitable and a system was developed to cater for the eccentricity of load using tension piles. In most cases three piles were used at each column, with a single pile in tension.

A pre-contract trial pile was specified for the first phase with the results also being used for Phases 2 and 4. On Phase 3 an increased factor of safety was used (2.5 instead of 2.25) to avoid the need for a further test; it was calculated that the cost of the resulting additional length of each pile would be less than that of a test, and additionally would not affect the programme.

Contract arrangements

Phases 1 and 2 were carried out under the 1963 RIBA Form of Contract. In order to obtain some appreciable degree of overlap between the two contracts on adjacent sites sharing the same limited access, the Phase 2 contract was negotiated with Trollope and Colls Ltd., the contractor on Phase 1; the latter contract had been awarded on the basis of a conventional tender.

Phase 3 was again put out to tender, this time using the 1980 JCT Form of Contract, on the basis that this was a separate site and the construction would not affect any rights of access, etc., granted under Phases 1 and 2. In the event the reverse situation occurred: Phase 2 was completed considerably behind programme and the scaffolding to the Lovat Lane elevation delayed the Phase 3 contractor, Wates Construction Ltd., from erecting scaffolding in the same narrow lane for Building AB.

Phase 4 was again negotiated with Trollope and Colls to gain a further time advantage in completing the entire development; this enabled an earlier start to be made as an overlap with Phase 2 could be achieved. JCT '80 was also used for this contract but with all sub-contractors taken on as domestic. This seems to be becoming an increasingly common client requirement and presumably one which causes some misgivings to the Joint Contracts Tribunal, bearing in mind the numerous and lengthy clauses on nomination in JCT'80.

The development

Those buildings which have been refurbished tend to be fairly plain, with brick facades unadorned by the features which characterize the new City Village buildings. They are however obviously not unrepresentative of the original character of the area and they do possess a certain elegance. The new buildings are more ornate, with extensive use of stonework, copper cladding on roof features and external metalwork. The most striking building is AB, which has an octagonal tower on the corner of Lovat Lane surmounted by a tower of reconstructed stone topped with a copper-clad dome and a weathervane in the form of a fishing boat. Part of the Monument Street facade has also been constructed as an exact replica of the original after a protracted battle with the planners to demolish the latter, which was in extremely poor condition and which we concluded was unstable; this was the so-called 'Terracotta Facade' and the new wall is also partly faced with terracotta blocks, copied from the originals, which are particularly attractive.

Lovat Lane itself is a very narrow pedestrianized street, where individual elevational features perhaps have a greater impact rather than entire buildings, due to the limited perspectives which are possible.

The concept of the City Village has attracted a certain amount of comment in the national and architectural press, not all of it favourable, but the development is at least established on the map in consequence.

Conclusions

The four phases of City Village were completed in almost exactly four years when Building M was finished in May 1985. The cost will be somewhat in excess of £10m. excluding land purchase costs.

Schemes are currently being examined for upgrading one of the original refurbishments, partly as a consequence of comparisons made with the new buildings by potential tenants.

We found a straightforward structural solution to suit the particular constraints of the development and we were content to retain it after a satisfactory trial on Phase 1.

This had obvious advantages and left us with relatively more time to concentrate on the particular problems of each phase, such as the deep underpinning on Phase 3 and the extreme lack of verticality of the Phase 4 party walls. We also found that on all phases the structure was completed with few problems and, where not affected by circumstances beyond our control, ahead of programme, which really speaks for itself.

Credits:

Client:
Guardian Royal Exchange Assurance

Architect:
The Thomas Saunders Partnership

Quantity surveyor:
Wicksteed, Son & Few

M&E consultants:
The Williams Sale Partnership
Buildings D,R,S, and AB
Max Fordham & Partners
Buildings Q and M

Main contractor:
Trollope & Colls Ltd.
Buildings D,Q,R,S&M (Phases 1,2&4)
Wates Construction Ltd.
Building AB

Farnborough Road office development

Architects: Scott, Brownrigg and Turner

Svend Jensen
Peter Lunoe

Introduction

Concrete versus steel-framed construction is an argument which has been going on for 50 years or more. The deciding factor is generally cost, which depends not only on prices of materials and labour but also changes in design criteria, technical development and new construction techniques.

Since the 1950s concrete has been the obvious choice for medium-rise buildings in the UK but over the last few years steel has made a strong come-back.

This is partly due to the current low, it could be claimed artificially low, cost of steel but the most significant factor is the use of composite construction with metal sheet decking.

This form of construction is common in North America and most of the developments which have taken place over the last 10 years have been pioneered in the United States. These include techniques for through-deck stud welding and also improvements in steel sheet profile with specially designed indentures to increase the load-bearing capacity of the sheet itself and improve the shear bond properties between the decking and concrete.

Within the UK there is now a considerable interest in composite structures encouraged by CIRIA and Constrado who have published a number of design guides, standards and technical notes.

Composite construction does offer a number of genuine advantages but some of the claims made on its behalf appear to be overstated, particularly as regards capital cost, in our experience it is now standard procedure to compare steel and concrete at the early scheme design stage and in recent exercises of this type we have, in each case, found the concrete structure to be cheaper in actual construction cost. However, once the cost benefit of the shorter construction period for the steel frame is assessed, this picture can change.

Concrete and steel are of course not directly interchangeable; each project must be considered individually as the general form of the building and choice of structure are interrelated. Composite construction will offer maximum advantage if the following situations apply:

(1) Rectangular plan layout with repetitive elements
(2) No (or very small) cantilevers
(3) All steelwork within the external cladding to avoid concrete encasement
(4) Lightweight curtain wall cladding which can be erected without scaffolding
(5) Finishes of dry construction which can be put up quickly
(6) No severe height limitations (for spans in the 6 to 7.5m range the structural floor depth increases by about 150mm when compared with flat slabs).

One building, where most of those points were fulfilled and where the comparison clearly favoured a steel structure, is the recently completed Farnborough Office Development for County and District Properties Ltd.

General description of the building

The building occupies a prime site at the north-east side of the Clockhouse Roundabout close to the centre of Farnborough. The site measures roughly 150m by 140m and has a slope of 7m from north-east to south-west.

The building, with a gross floor area of approximately 10,000m^2, has a cruciform plan shape (see Fig. 2). The central area and two of the wings are five storeys high and the two other wings, designed to have a roof garden, are four storeys. The central area is the only part of the building to have a basement and it also has a substantial plantroom on the roof. The entrance hall in the west wing is double storey height and partly open to allow cars to drive up to the main entrance (see Figs. 3 and 4).

The main core is in the central area, with smaller cores which house escape stairs and duct risers at the end of each wing.

The planning module is 1.5m and the wings have the normal office width of 13.5m with central columns dividing it into 6 and 7.5m spans. The longitudinal column spacing is 6m increasing to 7.5m adjacent to the central area.

The external elevations are clad in *Coolite* mirror glass which reflects 83% of solar heat. The cladding is made with structural silicone double-glazed units and is claimed to be the first project of any size in Britain using silicone bonding on all four edges. The exposed columns have an aluminium casing with polyester power finish. Solid panels with similar finish are also used at the secondary cores, alternating with vision panels of mirror glass.

The building is fully air-conditioned with a VAV system using ceiling-mounted slot diffusers. Heating is provided separately by specially designed perimeter-mounted radiant panels where the piped water services, together with electrical services, are distributed through the raised access floor.

Within the 1.8ha site there is a circulatory road system and parking for 333 cars arranged in terraces separated by planting. The external works also include a number of retaining walls and a 21m by 11m shallow pool, an architectural feature which doubles as a regulator for the surface water drainage system.

Contract and programme

From the start the client made it clear that he was looking not just for a strict budget but also for a tight overall programme to give earliest possible completion.

Scheme designs started in January 1983. The studies of concrete and steel options quickly showed that a composite steel structure would result in a two months saving in construction time and that the financial benefit of an early completion completely outweighed the additional cost of the steel structure.

The site start was fixed for 15 August 1983 with a 65-week contract period. To get a contractor abroad at an early stage a Preliminary Enquiry Document, fairly similar to a Bill of Approximate Quantities, was prepared in March and this formed the basis for appointing Costain Construction Ltd. as main contractor. During the design process Costains were involved in the planning and programming, advised the design team on constructional aspects and attended meetings with prospective sub-contractors.

Fig. 5 shows the construction programme for the structural work in a slightly simplified form. Erection of the steelwork was planned to commence seven weeks after site start. To allow for the ordering of steel sections, preparation and checking of working drawings and the actual fabrication, tender documents were issued at the end of May. The lowest tender was submitted by Octavius Atkinson who were appointed towards the end of July, 10 weeks before start of erection.

To speed up construction, the steelwork rises directly from the foundations including the stanchions in and around the basement. This allows the upper floors to be completed in the shortest possible time so that key activities such as roof waterproofing, curtain walling and installation of services can proceed in parallel with the more time-consuming concrete construction in the underground ducts and ground floor.

Substructure and ground floor

The site investigation showed approximately 20m of Barton Sands overlying Bracklesham Beds. Settlement calculations based on static cone penetration tests confirmed that it was acceptable to found the building at high level in the Barton Sands with a safe bearing pressure of 200kN/m^2.

For ease of construction, strip footings, running the length of the wings on the column lines, were used instead of individual pads. Adjacent to the basement the strip footings were stepped down using mass concrete.

The basement is close to the water table and as the ground is slightly acidic, with Ph values down to 4.5, an external membrane was used to provide watertight conditions and at the same time protect the concrete from acid attacks.

The basement excavation was done in open cut with steeply battered side slopes up to 7m deep. When wet, the Barton Sands turn into slurry and the excavations were therefore protected by polythene sheets and a system of drainage channels.

The suspended slab over the basement is 325mm solid reinforced concrete. The ground floor slabs in the wings incorporate underground ducts which carry air-conditioning and other services between the basement and the secondary cores at the end of the wings.

There are a couple of structural features in the main entrance hall. The staircase to the first floor gallery is a thin helical slab which, supported only at the top and bottom, curves through 180 degrees. As a visual counterpoint to this stair there is a 'water feature', a helical reinforced concrete cantilever, with a water cascade and planting. The formwork for both these structures, which can just be seen behind the curved glazing in Fig. 3, was quite complex and the contractor made a very good job of the construction.

Design of the superstructure

At the time we did the design the composite beams/profiled metal decking method of building was still very new to this country. Consequently up-to-date design methods were not yet covered by British Standards. We based our design on the 1983 CIRIA Report *Composite construction using profiled steel decking*. This document is supported by various research data and technical articles, particularly as regards shear studs/concrete interaction, and is generally in line with the ECCS European Recommendations.

Full plastic design is used for checking ultimate strengths, with partial safety factors for loads and materials similar to those in *CP110*. Using the 'partial-interaction' method of design as described in the above CIRIA Report, the ultimate steelwork and concrete stresses are first checked for a full plastic distribution and the shear connector requirements for this are then calculated. Where appropriate the number of shear connectors may be reduced which effectively reduces the concrete stresses and increases steel stresses from the fully composite condition. This is then followed by a number of serviceability checks to ensure that the steelwork stresses under wet concrete, short and long-term deflections are satisfactory.

By elastic design the shear connector requirement varies along the length of the beam but using plastic design the studs can be placed at uniform spacing with the proviso that a serviceability check must be carried out on the peak stud force at working loads. In this country a standard size and type of connector is almost invariably used, a 100mm high by 19mm diameter headed stud made from low carbon St 37-3K mild steel to the German Standard *DIN 17100.* The advantage of this is that the stud has good welding qualities, its general properties and installation requirements are well established and the necessary equipment for site welding is readily available. The stud-to-concrete compressive force is dependent on the concrete geometry between adjacent decking ribs and the concrete grade and type.

One of our early studies was to investigate the steelwork arrangements for secondary beams at 2m, 2.5m or 3.0m centres. These spacings cover the practical range of spans for the profiled decking; any greater spacing would require temporary propping of the decking during concreting. Our study showed the 3.0m spacing to be the most economic and it is also the maximum permitted span under GLC regulations when adopting a Restricted Fire Engineering approach to the decking.

Figs. 6 and 7 (overleaf) show the structural arrangement for a typical bay in the wings. The secondary beams are 305mm deep UB sections and the primary beams 356mm UB's, all in grade 50 steel. The metal decking is *Holorib* with cold formed edge trims in galvanized steel, strapped back to the sheeting. The overall thickness of the deck is 125mm with normal grade 30 concrete.

While the general wing beams had an efficient balance of concrete and steel for composite design, different considerations applied to many of the core beams. Loads were heavier because of blockwork walls and screeded rather than modular raised floors. Services openings and lift shafts reduced the composite action available from slabs and, of course, the services engineers particularly wanted to maximize the zone available for themselves with a consequent minimization of structural depth. Judicious re-arrangement of beam layouts plus a little extra reinforcement of the critical areas enabled us to satisfy all the requirements.

Columns were designed to *BS 449,* typical internal stanchions being 254 × 254mm UC sections and perimeter stanchions 203 × 203mm UC's. On the north, east and south wings the cladding steps in 900mm below the first floor as can be seen in Fig. 10, so the perimeter stanchions become external and are concrete-encased. On the west wing the cladding runs across the soffit of the second floor, giving the clear double-storey height area in front of the entrance hall, see Fig. 4. All stanchions here are concrete-encased and designed as such. The encasement was most important in reducing the slenderness ratio of these columns.

By efficient design of the steelwork, both in the overall arrangement and of the individual members, the tonnage required for the building was kept very low. The weight of steelwork members equates to 35 kg/m^2, a figure which compares very favourably with other steel-framed buildings.

Steelwork connections

For the steelwork connections we followed the normal practice of showing the structural requirements, in terms of design reactions and moments, on a specific set of drawings, enabling the fabricator to design and detail the joints to his own preferred methods. The steelwork connections were required to take the full beam reactions and moments as we considered little contribution could be gained from the concrete of the composite section.

As a rule secondary beams were designed as pinned each end, perimeter and spine beams as having partial fixity. The fabricator chose not to have bearing cleats but end plates for all beams, and designed a set of joint types following standard principles. Secondary beam connections were entirely within the steelwork depth, primary beam connections utilized the depth available within the concrete zone. For those situations where stanchion web stiffeners were necessary, he used web thickening plates on the principles developed in recent years and shown in the Constrado Manual of Connection Design. By comparison with traditional stiffeners at

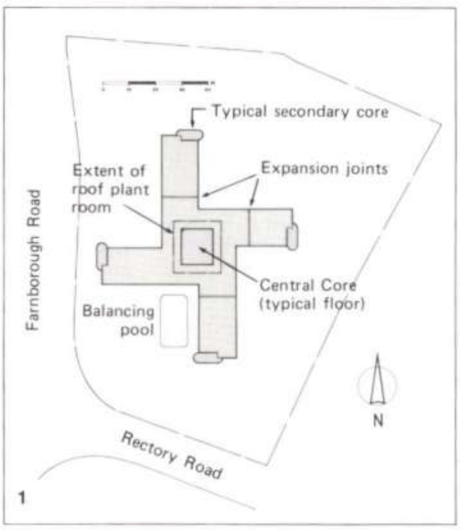


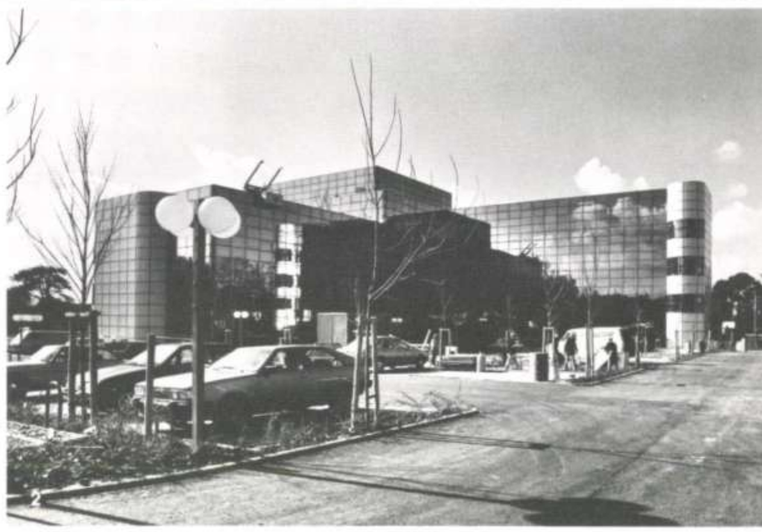
Fig. 1
Site plan

Fig. 2
View from north-east

Fig. 3
Main entrance hall

Fig. 4
Erection of steel frame
(Photo: Costain)

(**Figs. 2-3**
Photos: Ernie Hills)



right angles to the web, this method is of great benefit where beams are connected to the stanchion from two or more directions.

Stanchion splices were initially stipulated as being to full strength of the section, bearing in mind that most stanchions were designed to 90-95% of their capacity and some a little more. The fabricator chose to splice stanchions 500mm above second floor level, and proposed end bearing for axial load with normal bolting/plates for moment capacity. After inspecting his works and the quality of machining, we agreed to the end-bearing proposal. To assist him we also gave more specific design values for stanchion moments at his chosen splice locations, enabling him to minimize the bolting/plates requirements.

Stability

For structural stability the cruciform building shape is very suitable. Diagonal bracing is provided for both directions in the central core and for the transverse direction in the escape stair cores, at the end of each wing. The locations of diagonal members had to be co-ordinated with services ducts and doorways into the cores, so each elevation of bracing is designed as an N-truss arrangement. To allow for any direction of wind loading, diagonal members were designed both for tension and compression, using square hollow section steelwork.

Expansion joints are provided towards the inner end of three of the wings, at locations chosen to give simple detailing. To permit longitudinal movement but provide transverse stability the joints were made as sliding joints with dowels in the concrete deck. Longitudinal stability for these wings is provided by the spine beams and columns acting as moment frames.

As the west wing stanchions rise clear up to the second floor, it was logical not to have an expansion joint for this wing but provide longitudinal stability to it from the central core. Providing bracing to the wing in this manner is also of benefit in the design of the individual stanchions, because of their slenderness.

Stairs

The concept of straightforward steel erection, concrete cast on permanent decking and no propping, is carried throughout the superstructure including the stairs in the central core and at the end of each wing. Fig. 9 shows a stair core during construction.

Each flight is a shop-fabricated steelwork unit, bolted on site to the landing beams. Each step of the flight is formed from a steel plate bent to give a 75mm deep tray, which is then filled with normal concrete after steelwork erection. This gives the final stair ready for carpeting.

For the semi-circular landings the primary steelwork is two 150mm square hollow section members, welded to give a T shape in plan. The outer edge is a curved 100 x 100mm angle, acting both as edge former and structural member. *Holorib* profiled decking and concrete then complete the landing on site, again ready for carpeting.

The stairs and landings are simple in concept and construction. What is not so obvious is the care required in design and detailing to achieve this. Stairs often throw up problems disproportionate to the amount of work in them, and the ones in this building were no exception. For example the secondary core landings lie outside the perimeter line of stanchions, giving a most distinctive feature to the final building. However, the resultant force eccentricities, at mid-height level on the stanchions, proved quite a problem. Some specially-shaped brackets, fitting completely within the stanchion flanges so as not to protrude either into the cladding zone or the stairwell, were the answer.

Structure-borne noise and vibration

The steel-framed structure, being lighter and generally more flexible with a lower damping capacity than that of an equivalent concrete structure, is more susceptible to vibration. However, calculations indicated that the structural response of the building is perfectly satisfactory for normal office use.

Although most machines and items of plant vibrate at frequencies well below the audible range, the low frequencies can be felt and there is a danger that they may induce high or audible frequencies in some part of the building, even far away from the source. To combat this the roof plantroom has a floating floor made with an independent, mesh reinforced concrete slab cast on a metal decking, which is supported from the structural floor by resilient rubber pads. Apart from acting as a structural isolator the floating slab adds to the general mass of the floor structure and provides high frequency attenuation.

Corrosion and fire protection

The question of corrosion protection of the steelwork was discussed with the client at a very early stage and it was agreed that although it was basically in a dry, internal environment some form of protection should be provided. All the internal steelwork, apart from the top flange of beams to which shear studs are welded, has been painted with a two-pack epoxy primer. In addition the members along the perimeter, which are more likely to become damp, were given an MIO barrier coat.

The superstructure was required to have a fire resistance of one hour and for internal beams and columns this was achieved by a vermiculite spray, *Mandolite P20*, and by fire blankets at the expansion joints.

The external stanchions at ground and first floor were encased in concrete, with a 50mm mesh reinforced cover, after erection.

As far as the deck is concerned a Restricted Fire Engineering Approach was adopted to calculate the extra fire reinforcement which, in addition to the A98 mesh in the top of the slab, amounted to an 8mm bar in the bottom of each rib, ie at 150mm spacing.

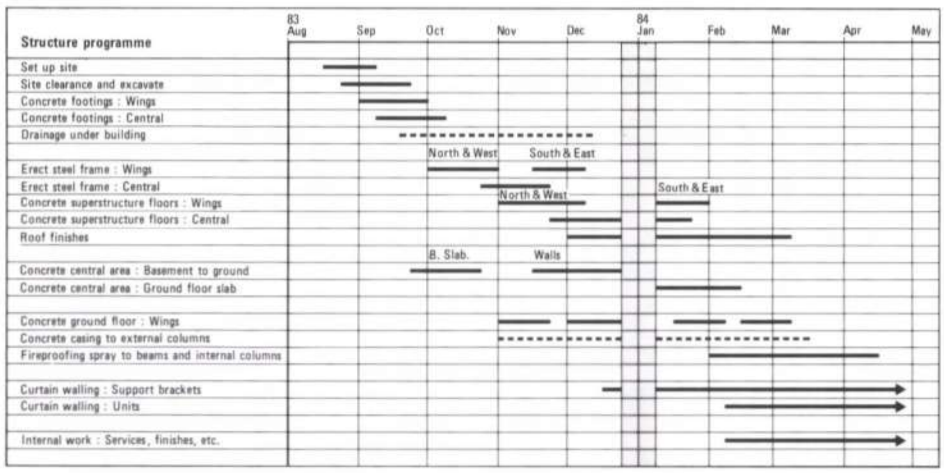
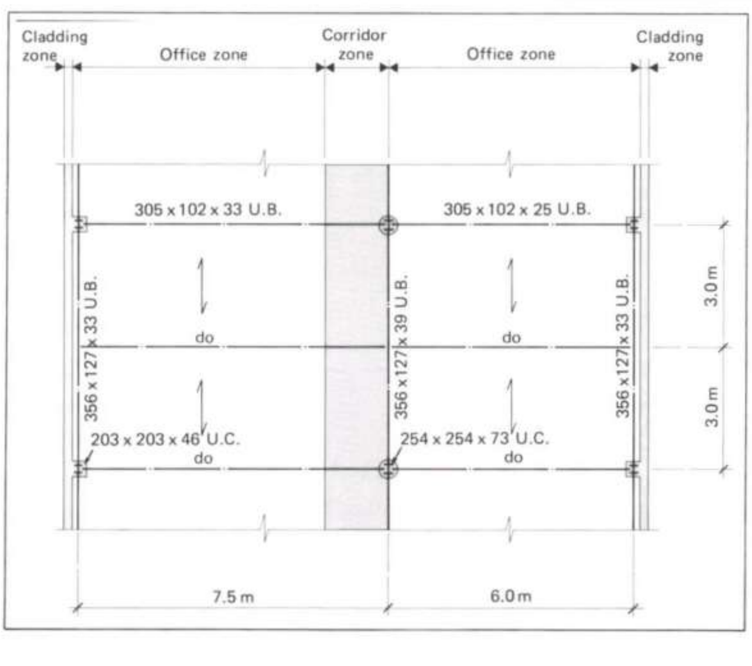
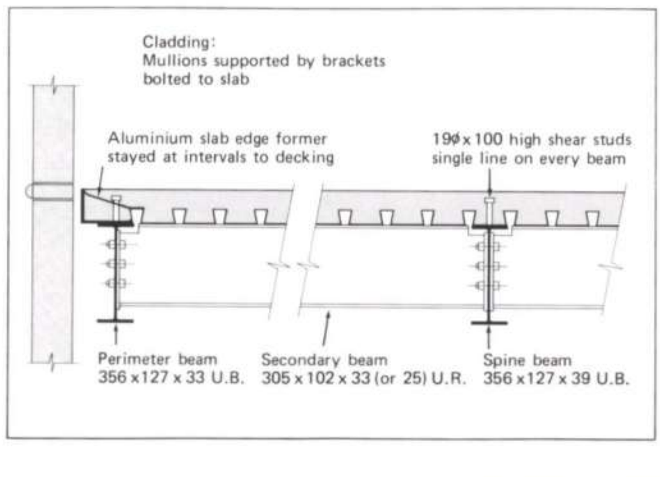


Fig. 5
Programme for the structural works

Fig. 6
Layout of typical bay

Fig. 7
Typical cross-section through deck





Practical matters

With traditional concrete construction there are practical aspects which, because they are so familiar, are often taken for granted by the design team or left in the capable hands of site staff and the contractor. Similarly with composite construction there are many practical aspects but in contrast these should be considered by the design team.

Steelwork erectors are permitted to work without all the safety rails required for general labour gangs. This is one advantage in having the profiled decking included with the steelwork sub-contract, so that the erectors also lay the decking. However safety rails will then be required before reinforcement fixing and concreting.

The spacing of shear studs should be a multiple of, or the same as, the decking rib centres where the decking crosses the beam. Conversely where the decking is parallel to a beam, it should be arranged so that the ribs are spaced equidistant about the centreline of the beam.

Site testing of the shear studs is very simple. A small proportion are bent over to 15° from the vertical, usually with an odd length of scaffold tube. If a stud detaches, or a visual inspection shows any fractures in the weld, then it is condemned. On this project we found that generally studs welded through a single layer of decking were all sound, whereas in the few places where two layers of decking or a layer of decking plus a layer of edge trim occurred, the studs detached. The site test seems crude but appears to be quite effective.

Large holes for lifts and such like are formed by the decking laid to suit with edge trim all round. Smaller holes for services can more conveniently be formed by running the decking through, boxing out prior to concreting, then cutting the deck afterwards.

Because of the timescale of erection and the comparatively small quantities involved, the contractor will generally be looking to pour quite large areas of concrete at a time. On Farnborough where the concrete was pumped and power-floated, the contractor was aiming to concrete one floor per day in each wing. Although this was a little optimistic for the first wing where a learning curve situation applied, he did achieve it for each of the last two wings.

Fig. 8
Roadway under west wing
(Photo: Ernie Hills)

Fig. 9
Escape stair in wings
(Photo: Svend Jensen)

Fig. 10
View along south wing
(Photo: Ernie Hills)

Conclusion

The Farnborough Office Development has clearly demonstrated some of the advantages which can be gained by using composite construction in the right circumstances; given the high standards required, the building has been completed quickly and at a relatively low cost.

Credits

Client:
County and District Properties Ltd.
Architects:
Scott, Brownrigg and Turner
Quantity surveyor:
Banks, Wood and Partners
Services consultant:
Michael Aukett Associates
Landscape consultant:
Eachus Huckson Partnership
Main contractor:
Costain Construction Ltd.
Steelwork sub-contractor:
Octavius Atkinson & Sons Ltd.

Printed in England by Reedprint Limited, Windsor, Berkshire