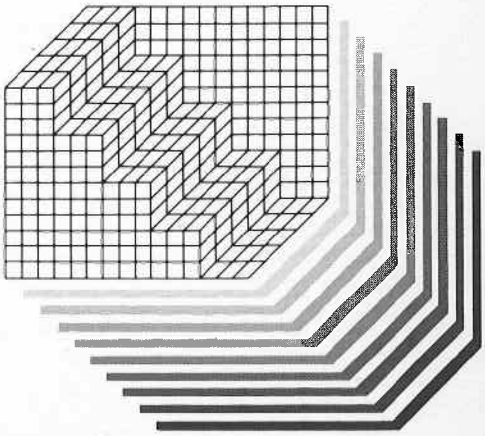
Patterns 6



1987

Patterns 6

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Editorial Foreword

In Patterns, engineers of different disciplines and differing views are asked to write about our experiences. The editorial instruction to each author is to try to explain the engineering thought processes that went into the advice given on a particular project, and then to describe the influence such thoughts had on the evolution of the 'pattern' of that design. Clearly, this involves some description of the development of both the technical solution, choice of materials and of the overall design. With due application of science and design method alongside others of the design team, the project should then achieve its intended 'function' and 'design life' in the context of its desired aestheticism and cost.

This issue describes the evolution of a range of projects designed to high standards to satisfy the changing circumstances of modern commercial life. Each of them is, we believe, in some way innovative. In fact, most modern buildings are by their nature innovative and may use materials in a way that is different from traditional usage. We have entered a new decade – one of changing circumstances, and in the UK we experience a testing natural climate. It therefore seems appropriate that Professor Bill Biggs, who heads up our small, emergent Building Maintenance Group, should write by way of an introduction to this issue about his approach to the use of materials in the built environment.

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Those Ills We Have

"... puzzles the will
And makes us rather bear those ills we have,
Than fly to others that we know not of."
Hamlet, III, i,56.

The *total performance* of a building refers to its ability to fulfil its *intended function* over the whole of its *design life*. Leave, for the moment, the rather woolly concepts invoked by the terms *intended function* and *design life* – we will return to these later. Meanwhile we assume that what we are talking about is not only the logic and effectiveness of the spatial relationships within the enclosure but also the performance of the enclosure itself. And that includes every possible aspect – technological, social and economic. For it is generally true to say that buildings become unserviceable – that is to say uneconomic – long before they become unsafe. This is certainly true of the external fabric. An understanding of the deterioration processes here is based, largely, upon traditional, empirical concepts having little basis in the physical and chemical laws which determine the long term behaviour of building materials.

No material resists the action of the atmosphere for an indefinite period – the second law of thermodynamics sees to that – and when we consider the number and type of deteriorative elements that exist in the natural world it is remarkable that materials last as long as they do. The terminology is confusing and often misleading. The term *deterioration* has emotive overtones since, in dictionary terms, it is "the process of becoming worse" – though worse than what it is difficult to say. For architects and estate agents it is often replaced by the term *weathering* which is considered to be pleasing and is generally reflected in the price. So when, we may ask, does *weathering* become *deterioration?*

Durability is equally hard to define. The BSI Code of Practice describes it as *the quality of maintaining satisfactory appearance and satisfactory performance over its life.* Note the order – maintaining appearance is apparently more significant than maintaining performance. Durability, in fact, is not a single property like, say, strength or hardness – rather it is the consequence of the interaction of many factors such as the fitness of the design for the intended use, the quality and type of materials used, the stability of site, the degree and type of exposure.

The first of the ills we have to bear is our climate. On the whole it is a pleasant one in which to live but, for building materials, it is one of the most testing in the whole world. Warm, moist air from the south and south-west collides with cold, dry air from the north and north-east. At any time in summer it is probably raining somewhere and at any time in winter it is freezing somewhere. Every few years we get a prolonged dry spell – in summer materials dry out, in winter there is severe freezing. The humidity is not very high, but it is consistent and the number of freeze-thaw cycles is probably greater than anywhere in the world. Wind speeds are variable – gusting causes the most damage and is to be expected in the wettest regions and at the wettest time of the year. As Bill Allen (Ref 1.1) says "It is a challenging environment demanding respect, and our failure to give it during the recent changes from traditional to innovative design and construction explains many of the problems that have lately arisen". And, you will note, I have made no reference to man-made pollutants – the climate is already tough enough without these added hazards.

Taking the broad view, there are some compensations in what seems at first sight to be a rather gloomy picture. The moisture that rusts steel is essential for maintaining the good qualities of paper; the sunlight that destroys a paint film is also responsible for preventing fungal growth upon that same paint. Reduced to its simplest terms the problem resolves itself into that of keeping the wrong elements out and of putting the right elements in. Take, for example, moisture ingress into a building. There are only three factors involved – there must be moisture available, there must be some form of passage through which it can travel and there most be a pressure difference to drive it through. Control, or preferably eliminate, any of one of these and the problem is solved. And in solving it we probably create a different set of problems thus, if we seal the wall to keep the moisture out we also keep the moisture in and lo and behold – condensation with all of its attendant problems.

There is, probably, no area of materials science where the gap between "theory" and "practice" is so wide. Every situation needs to be examined on its own merits since each will involve some departure from the ideal – and it is often the small departures which pose the greatest problems. But deterioration is inevitable – the chemical and physical laws which operate are unalterable. The concept of a non-deteriorating or maintenance free building is a pipe dream. The best that we can ever do is to control the rate of deterioration though it often happens that through inadvertence or ignorance we often speed it up rather than slow it down.

Thus it would be foolish to try to assign reasons or to try to generalise too much. But the second ill we have to bear – albeit with some pride – is that British designers and builders are among the most innovative in the world and many of our troubles may be ascribed to this fact. Designers take on the solving of problems, and the logical solution to the design problem often leads to a certain combination of materials which may be unfamiliar. But although building has become more of a science based rather than a craft based industry, the people within the industry have not until very recently been educated to deal with the impact of science.

Regrettably innovation has, all too often, caused the juxtaposition of phenomena each of which was fully understood separately from a scientific point of view. But, put them together and trouble is in store. Two simple examples will serve. Concrete cures slowly over several years. The process involves a progressive loss of moisture and leads to a slow, but inexorable contraction. Kiln fired products such as brick and tile arrive bone dry and absorb moisture over time. In so doing they expand. Both phenomena have been known, and understood, for many years. But put an expanding overlay upon a contracting base and you are in for trouble. The susceptibility of steel to corrosion by chlorides has, I suspect, been known ever since the first steel ship was launched. And yet chlorides were freely used as accelerators in reinforced concrete. Moreover the fact that the corrosion product of steel occupies much more volume than the steel itself and will, therefore, subject the concrete to tensile stresses which it cannot carry, it is also not new. After all, Mnesciles when building the great gateway to the Acropolis – the Propylaea (begun 437 BC) – used iron rods to reinforce the marble beams. Even this was not particularly advanced – the same system was used as early as 470 BC. And in both cases, they got the depth of cover right. But the Victorian engineers used iron bands for strengthening – even the great I.K. Brunel discovered that using hoop-iron to strengthen brick work was disastrous – and costly. Historical precedent seems to have been largely discarded in recent years.

Change of use – often apparently quite minor – can lead to spectacular changes in the ability of the building to cope. Blocking up the fireplaces and sealing up the doors of draughty Victorian houses is fine – until you install central heating, a bathroom, a washing machine or anything else (and that includes people) which produces moisture. Cavity insulation is much advertised – but the cavity acts as a drying step for moisture penetrating through the outer leaf which is now insulated from the heat sink of the building and which will get wetter. All we now need is a few freeze-thaw cycles and we have serious frost damage to the brickwork. Here comes one of the evils that we know not of – yet. The answer – put the thermal insulation on the outside as we do on flat roofs.

The third ill that we must bear is *quality – quality assurance, quality management* etc etc. It is the flavour of the year ever since BS 5750 was published. But several things must be borne in mind before we climb upon this particular band wagon. The first is that we do not manage quality – we design and manage in order to achieve quality. Every consultant has that aim – and every client has a right to expect no less. The second is that, at the end of the day, the client determines the standard of quality – if he wants a Rolls-Royce that is what he shall have (and pay for) but if an Escort suits him that is what he will get. The basic trouble here is that architects, designers and, perhaps most importantly, the various building standards set one level only – the Rolls-Royce syndrome and, mostly, no alternative is considered. Quality is not perfection and the pursuit of perfection is not only fruitless but expensive and, generally, doomed to a failure to live up to the promises made.

Earlier we referred to the term *design life*. This is a very recent concept. Less than a decade ago the phrase would strike panic into the minds of many of those concerned with building construction – and for far too many it still does (Ref 1.2). Buildings are meant to last for ever – are they not? – and obsolescence is a curious modern aberration. But take the manufacturer of a hi-tech product. The half-life of his product is now reckoned at about two years so that, in about four years he will need a new – or at very least – a completely redesigned and reserviced building. And, as the demands of the workforce in any building become more sophisticated so will it become necessary to think more carefully about design life. After all – you think about the replacement cycle of your car – why not about your building? It is, probably, your most expensive investment and preventative maintenance usually costs much less than emergency repair. There are, on the market, a number of computer programs which are designed to help – over the next few months we hope to evaluate these and to recommend the most appropriate one to the client.

But what of the ills we know not of? It would be a brave man to try to predict, but some trends are already giving cause for concern. Mismatch, as in the concrete/tiling problem noted above, is likely to become more crucial when contemporary materials are used to repair traditional materials – and especially those which have withstood many years of exposure and consequently of adaptation to the climate. Hewlett and Hurley (Ref 1.3) for instance, have pointed out that many of the polymeric materials commonly used in concrete repair have very different characteristics (thermal expansion, creep, stress relaxation) from those of the concrete itself. Another potential area for concern is the likelihood of increased usage of reclaimed or recycled materials and the development of new ones, especially if they are used before they have been sufficiently tested.

I am not saying that we should, as a matter of course, stick to those materials that we have traditionally used – though I confess to a great love for brick, tile, timber, steel, and even concrete (if it is sensibly designed and carefully detailed). What concerns me is that there is no really reliable test for the durability of a building material – except that of putting it in a building and waiting to see.

Accelerated tests are all very well – but they rarely correlate with each other and even less so with service performance though some preliminary results from Sweden show promise in certain areas.

Perhaps I can conclude with a cautionary tale. It does not concern buildings but with another, all too familiar problem, corrosion in motor cars. Some years ago a so-called "accelerated test" was devised (Ref 1.4). A car was driven at about 20mph through a salt bath and then into a humidity chamber where it was allowed to "sweat" for several hours. But 20mph produces large droplets of spray travelling fairly slowly – driving at 60mph on the motorway produces fine droplets travelling at about 120mph, these are self compacting and will not find their way ino the manufacturers drainage holes. And, of course, when cars were designed to pass the test rather than to meet service conditions premature corrosion became the order of the day.

Always keep your fingers crossed when you are told to select such and such a material whose "durability has been proven by accelerated testing". For materials are rather like people – their – performance is largely conditioned by the circumstances that surround them. As Donne says – "No man is an island, of himself entire". Equally no material, and no component exists on its own – it is a part of the whole building and must be considered as such. And a test, in the isolation of a laboratory does not, necessarily, demonstrate a willingness (or an ability) to perform well in a crowd.

Bill Biggs

References

1.1 Allen W. 'Root causes of degradation'. Design Life of Buildings, 1985, Thomas Telford, London.

1.2 Rose, G.M. 'Durability – who really cares?' Idem.

1.3 Hewlett PC and Hurley SA. 'The consequences of Polymer – concrete mismatch', Idem.

1.4 McArthur H. 'Motor vehicle corrosion'. Metals and Materials, January 1985.

Horsham Town Centre Redevelopment

Project data – Springfield Way

Client	RAPD (Horsham) Ltd
Architect	Franklin Stafford Partnership
Civil/Structural Engineer	Buro Happold
Services Engineer	Buro Happold
Quantity Surveyor	Walfords
Management Contractor	Laing Management Contracting
Completion Date	October 1989
Value	£13m

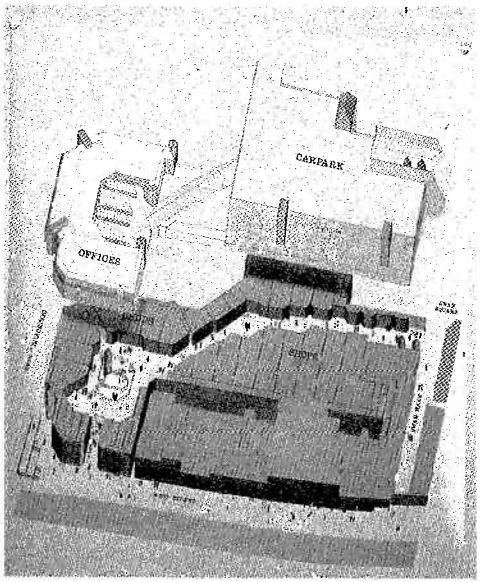


Fig 2.1 Axonometric of Springfield Court development

In 1980 developers Shearwater, with architects Franklin Stafford Partnership and Buro Happold, won the competition to develop a site between Springfield Way and West Street in Horsham. The proposed development had shops at the lower levels and offices at the higher levels on three sides, around an east facing courtyard enclosed with glass roof and inclined glass wall (Fig 2.1).

Having won the competition, Shearwater asked the architects and ourselves if we could see a way to link the new building with the existing Swan Walk shopping centre some 100 metres away across a large retail delivery yard. We took up the challenge and having looked at various arrangements of delivery area and retail mall levels, suggested the adopted layout with the service yard dropped by excavation, a retail mall linking Swan Walk with the upper level of new building and a multistorey car park over the retail (Fig 2.2). The construction cost of this link was high in relation to the lettable area of retail created, but Horsham District Council was keen to achieve the scheme's increased car parking and improved shopping facilities in the town centre. They were also landowners of the service area and a deal which made the development viable was agreed.

Shearwater decided to proceed and Associated British Ports joined them in the development forming a company called RAPD Horsham Ltd. The project is now called Springfield Court and comprises 50,000 ft² of offices on two floors, 37 shop units on two levels, 360 car parking spaces, a large underground service yard, and extensive glazed malls and courtyards.

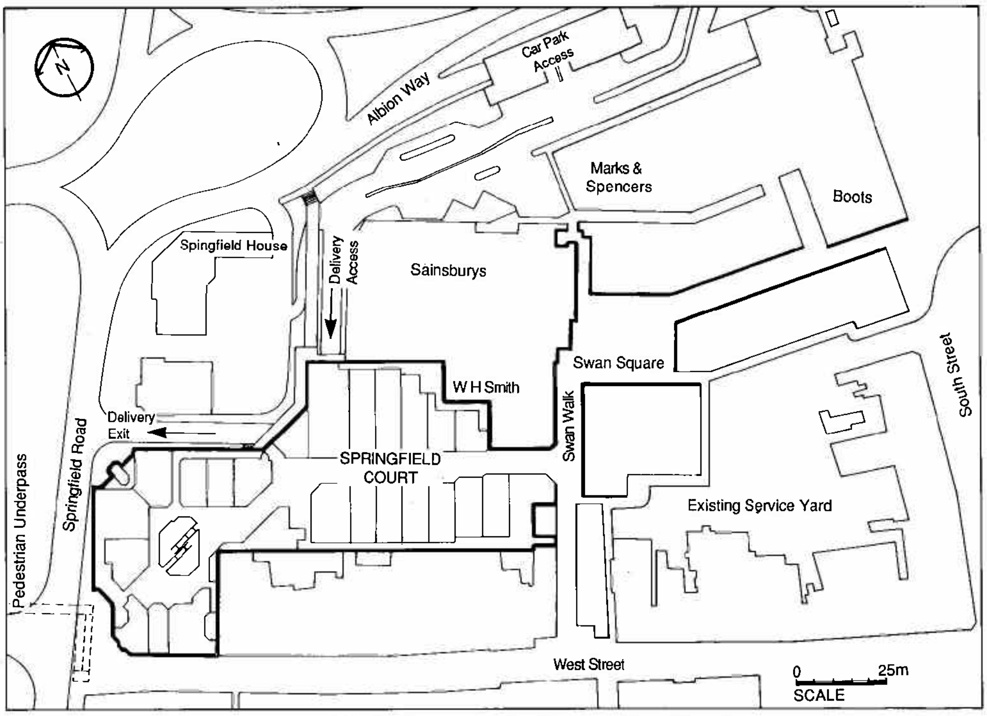


Fig 2.2 Site plan of Springfield Court and Swan Walk shopping developments, Horsham

Norwich Union who owned the existing Swan Walk shopping centre built in the early seventies and containing Marks & Spencer, Boots, Sainsburys and some smaller units, made two decisions. The first was to refurbish the existing centre to bring it up to a standard compatible with the new development giving all malls and courtyards glazed roofs, new floors, and walls and ceiling finishes. Renton Howard Wood Levin were appointed as architects and Buro Happold as structural and building services engineers for this project. The second decision was to buy the new centre from RAPD (Horsham) Ltd on completion and run both centres as one. As a consequence two clients, two architects and eventually two contractors were involved on two projects which were on completion to operate as one. Our involvement in both projects became of major significance in solving and implementing the fire engineering means of escape and alarm systems.

Redevelopment problems

Town centre redevelopment sites bring with them complex technical challenges. This one had more than most. It proved necessary to excavate and underpin below the foundations of many neighbouring buildings, move a major electrical substation, divert a main storm water sewer, redirect the vehicle flows within the existing multistorey car park, temporarily redirect the service vehicle movements to the existing centre, link the alarm and sprinkler systems of various existing shops to the new systems, rearrange the delivery and storage area of an existing Sainsburys supermarket to allow deliveries from the opposite side of the building without disturbing the operation of the sales floor, cut out an existing column below a 5 storey car park while it was in use and replace it with a new column in a different location, carry out the entire refurbishment of the existing Swan Walk centre with the centre open to the public, and temporarily reopen a pedestrianised street to major service vehicles. Some of these operations are described below.

Traffic movement within the development

In the original shopping centre, a mix of service vehicles and private cars had been allowed to both enter and leave the development causing congestion. Furthermore, buildings were serviced from various bays and there were often long queues back onto the highway. The delivery bays for the Sainsburys supermarket were also in direct conflict with development proposals and therefore needed to be relocated.

Many vehicle movement options were studied jointly with the highways department, and a layout

Project data – Swan Walk

Client	Norwich Union
Architect	Renton Howard Wood Levin
Civil/Structural Engineer	Buro Happold
Services Engineer	Buro Happold
Quantity Surveyor	Gordon Harris and Partners
Contractor	James Longley and Co
Completion Date	October 1989
Value	£4m

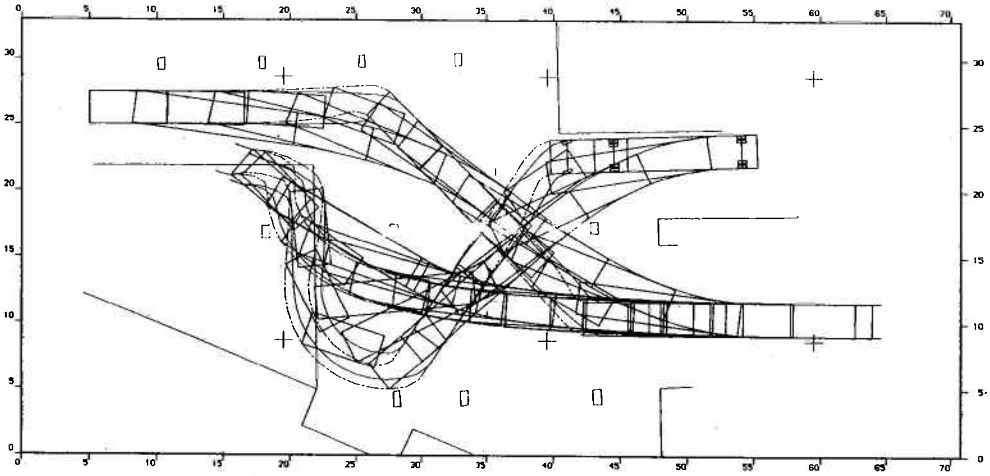


Fig 2.3 Computer simulated "swept path" diagram

Fig 2.4 Relocated column of multi-storey car park

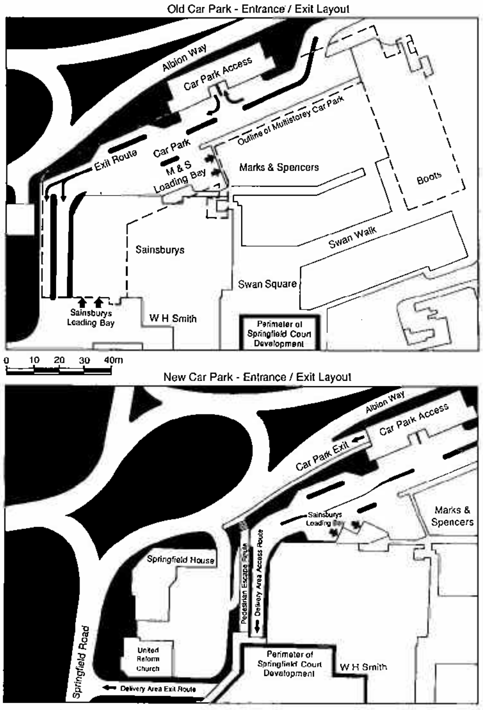


Fig 2.5 Rearrangement of ramps and exits within car park

providing a new roundabout access, separated service vehicle and private car routing, and rationalised service bays, was chosen. A new computer program was developed to study the "swept paths" of articulated and other vehicles accessing and leaving the bays (Fig 2.3), and full scale vehicle tests were carried out at the BOC depot to check the computer simulation of the Marks & Spencer bays.

Demonstration indicated that the resited Sainsbury delivery bays would only operate satisfactorily if one of the main multistorey car park columns was relocated. This was a ground to first floor column under a 5 storey car park with 12.5m beam spans. The new foundation and column was built in in-situ concrete, the relevant section of first floor was cut out and a new in-situ concrete beam formed to sit on the new column and collar the existing one (Fig 2.4). Prestressing was used to ensure the shear connection between the new and the old, and when the concrete was significantly cured the old column was removed. The whole operation was successfully carried out with only minor restriction to parking facilities.

The direction of flow in the car park ramps was reversed to better suit the new entrance and exit arrangement, and the construction of a new exit onto Albion Way completed the improvements (Fig 2.5).

Inverted syphon for stormwater

A 450m diameter storm sewer across the old service yard could not be dropped below the new service yard located at basement level. Furthermore no route could be found to take it round the perimeter. Other options were considered and as a result an inverted syphon design was developed as a solution with complex chambers at each end to allow cleaning and maintenance.

Electricity substation relocation

The main high voltage cables supplying the centre of Horsham cross the old service yard and one of the main 2.5 HVA substations was located at the centre of the yard. In consultation with the SEB a design was developed for a temporary substation and cabling, so allowing a rerouting of cabling through the new substation on its completion. The transfer from the existing substation to the temporary one, and subsequently to the final one, had to be phased to fit with the construction of the foundations and basement.

Underpinning of neighbouring properties

The basement area is bordered on three sides by existing buildings, and a variety of temporary works options were examined. The solution which was eventually adopted comprised steel king posts tied back with ground anchors at the top, and restraining timber sleepers. Underpinning of the adjacent properties proved to be necessary in many areas – notably the area of car park columns adjacent to the basement entrance ramp. In order to provide adequate width to vehicles it was necessary to remove nearly a half of the existing 4m square column bases to five of the columns. These bases were underpinned with a series of high capacity (500 kN) minipiles with new pile caps stressed to the sides of the existing columns with Macalloy bars.

Springfield Court – New structures

The buildings which were founded on spread footings onto the mudstone, are predominantly of in-situ reinforced concrete construction throughout (Fig 2.6a,b). The Garden Court structure is of ribbed slab construction with a steel framed mansard roof enclosing the upper level of offices and housing the roof top plantroom. The general structural planning grid is 7.5m square, based on the width of a typical shop unit. In practice, however, it was necessary to vary many of the spans and to transfer column positions between levels in order to maximise the lettable value of the retail space and to suit the mixed office and commercial link at the different levels.

The basement service area is of watertight reinforced concrete construction, while the lower two suspended floors in the mall area are of ribbed slab construction similar to that in Garden Court. In the upper storeys, which form the extension to the multistorey car park, the spans are increased to 15m to improve car park circulation and parking, and beam and slab construction is used for these levels. The two storey section of the building which forms the link between the car park and the Garden Court comprises shop units at existing ground level located above the new basement. (Fig 2.7). The upper storey of this section of the building is of steel frame construction as the columns between the shop units are located off grid from the basement below.

The main glazed roof atrium structure spans approximately 18m and is primarily supported on twin three pinned arches formed from rectangular hollow sections (Fig 2.8). All other primary members are supported on link plates and pinned connections. This structural system provides a high degree of tolerance during erection and allows for thermal movements of the steelwork relative to the support structure. The atria steelwork design incorporates integrated fixings for the glazing smoke vent support structure, and secondary steelwork supports to the external tracked maintenance ladder system.

The design of the mall roof comprises cranked rectangular hollow steel section beams supported on existing corbels between the shop units and supporting pitched glazing with a central horizontal section where smoke vents are located. As there was insufficient space for a centralised plantroom, mechanical extract and heating systems in self contained gas fired units are provided at several points on top of the roof structure. A tracked cleaning system is located outside the glazing and the mobile ladders also provide access to the plant platforms. Roof drainage is provided by edge gutters draining into new downpipes located behind architectural pilasters.

In the longer spans over Swan Square and at the entrance to Springfield Way, pyramid structures are formed using RHS on the diagonals tied by the glazing purlins.

Springfield Court – Building services

Buro Happold was responsible for the design of all building services and for all design negotiations with the public utilities companies regarding diversions and supplies to the new building. Responsibility also covered the overall fire protection scheme, including smoke control of the atria spaces and shopping malls.

The services design falls broadly into two categories – those of landlord and tenant. The landlord's services include the provision of gas, water, drainage, electricity and telecommunications, ventilation of the public spaces, exhaust extraction from the car park and basement service areas, lighting of the public spaces, and the provision of fire fighting and fire alarm systems, security and PA systems, and TV aerials and lightning conductors. These systems are

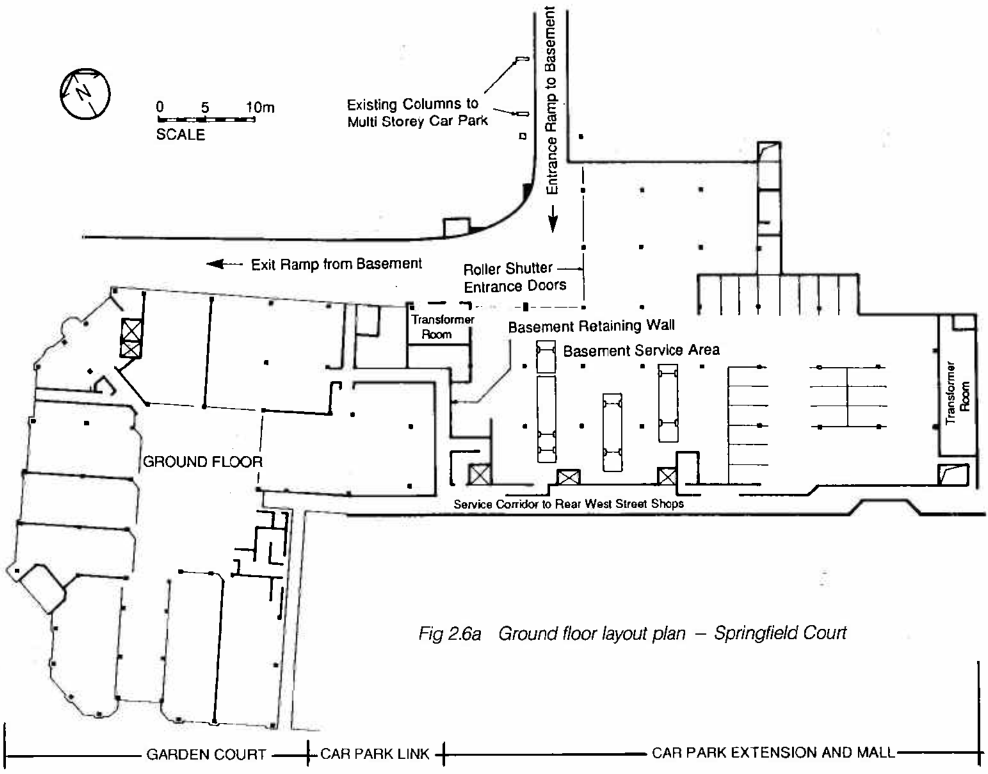
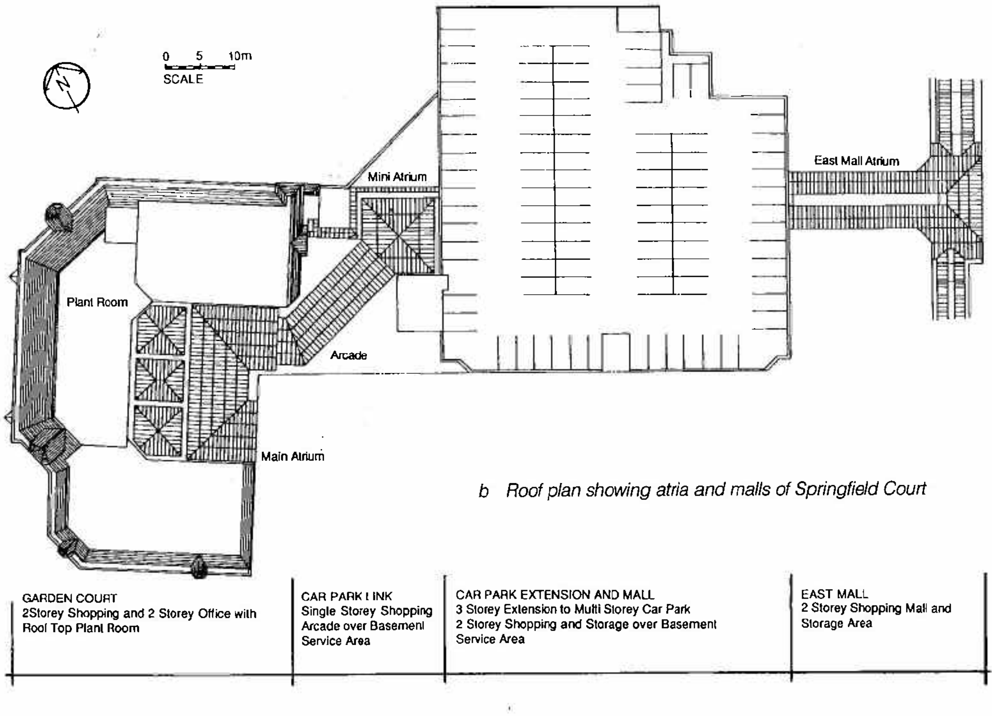


Fig 2.6a *Ground floor layout plan – Springfield Court*



b *Roof plan showing atria and malls of Springfield Court*

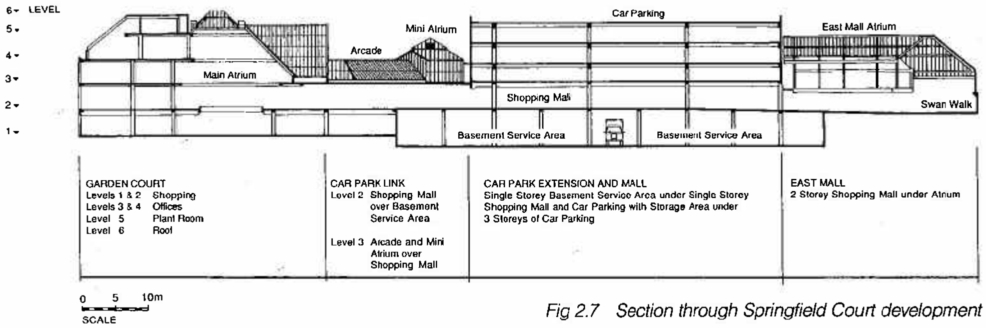


Fig 2.7 Section through Springfield Court development

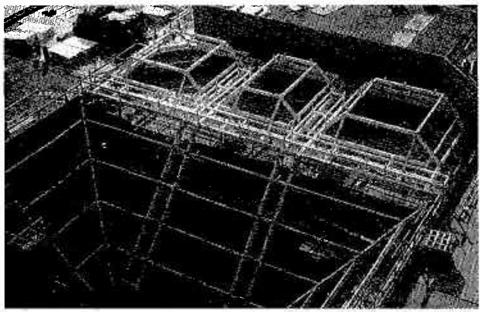


Fig 2.8 Construction of Springfield Court main atrium roof

monitored in a new management control suite located in the existing Swan Walk shopping complex. The two passenger lifts, scenic lift and escalators in Garden Court, and the two passenger lifts, four service lifts and two scissor lifts in the mall also fall within the category of landlord's services.

In general, each shop unit is provided with 'capped-off' services, the completion of the services installation within the shop being the responsibility of the individual tenant. A 3-phase electrical supply point is taken to each unit for power supply. In two instances, in shops which are allocated for potential catering use, provision has also been made for gas supply. Interface units are provided in the shops so that the tenants' fire alarm and security systems can be linked up to the main control room.

Water supply is provided to each shop unit by means of a 22mm dia cold water stub connection. A drainage stack at the rear of each unit enables the shop tenant to connect a wash basin and w.c. into the main stack. A stub connection from the wet sprinkler system is provided in each unit, terminating with a monitored isolation valve and flow switch. This is connected to the fire alarm system and monitored from the central control suite.

Provision has been made in the overall design to enable each tenant to install air conditioning or ventilation systems within each shop up to a maximum of four air changes per hour (Fig 2.9).

A comprehensive environmental study was undertaken to arrive at the optimum solution for the type of glazing in the roof structure, and to determine the required solar protection. Passive elements were used as much as possible to obviate the need for cooling. The study also compared natural and mechanical ventilation and expected peak summertime temperatures. Results showed that solar control glass (light transmission above 50% and solar radiant heat transmission of 65%) should be used to reduce both glare and direct sunlight, and that mechanical ventilation would provide full fresh air and air movement through the malls.

Refurbishment of Swan Walk

In the Swan Walk refurbishment it was decided firstly to minimise ductwork and secondly, for aesthetic reasons, to locate the plant on the horizontal element of the mall roof structure. Specially developed air handling unit assemblies comprising supply plant, return and supply attenuators/discharge plenums were provided. The units are circular in cross section, fully weatherproof and are totally self contained being supplied with gas and power from the main site utilities, and control from the management centre. Ventilation can be either full recirculation, full fresh air or a combination of both – exhaust air is by natural means utilising the horizontal louvres within the glazed roof structure. (Fig 2.10)

Rod Macdonald

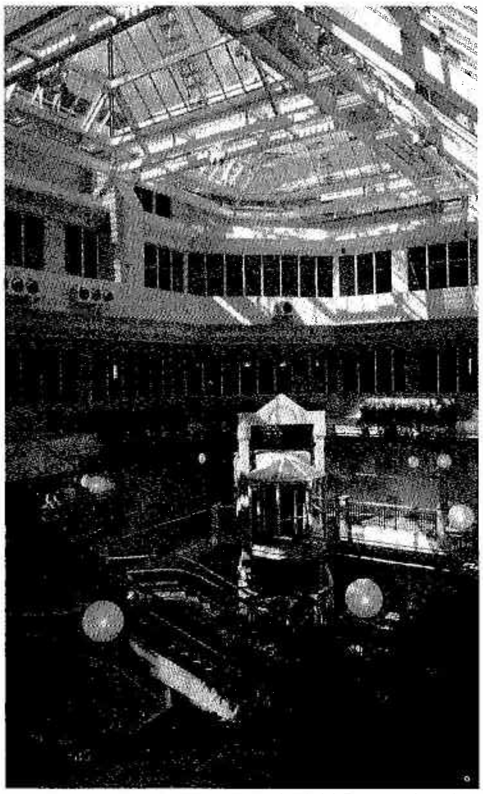


Fig 2.9 Interior of completed Springfield Court main atrium

Fig 2.10 New glazed roof of refurbished Swan Walk shopping mall

Warehouse and Office Development for Schwarzkopf UK

Project data

Client	Schwarzkopf UK
Architect	Denton Scott Associates
Structural Engineers	Buro Happold
Services Engineers	Buro Happold
Quantity Surveyors	David Langdon and Everest
Main Contractors	Western Counties Construction
Size	1800m² warehouse, 733m² offices
Cost	£1m
Completion	July 1988

The black silhouette of a woman's head is the famous Schwarzkopf logo which has appeared on all products since the founding of the firm in 1898, the word itself German for 'person with black hair'. Today Schwarzkopf is a worldwide organisation with an expanding manufacturing and distribution capacity in over 100 countries throughout the world.

Centre of operations for Schwarzkopf UK is located in Aylesbury, close to the town centre on a site bounded by a small stream and a railway. The existing production facility consisted of conventional steel and precast concrete frame buildings but was restricted by the lack of on site warehousing. Directors felt that they needed to improve the company's image for the 1990s and to achieve this aim they held a limited competition for the design of an 1800m² warehouse with 733m² of office accommodation for the marketing section. The entry submitted by Denton Scott Associates was judged the winner and they were subsequently appointed project architect, with Buro Happold as structural and services engineers.

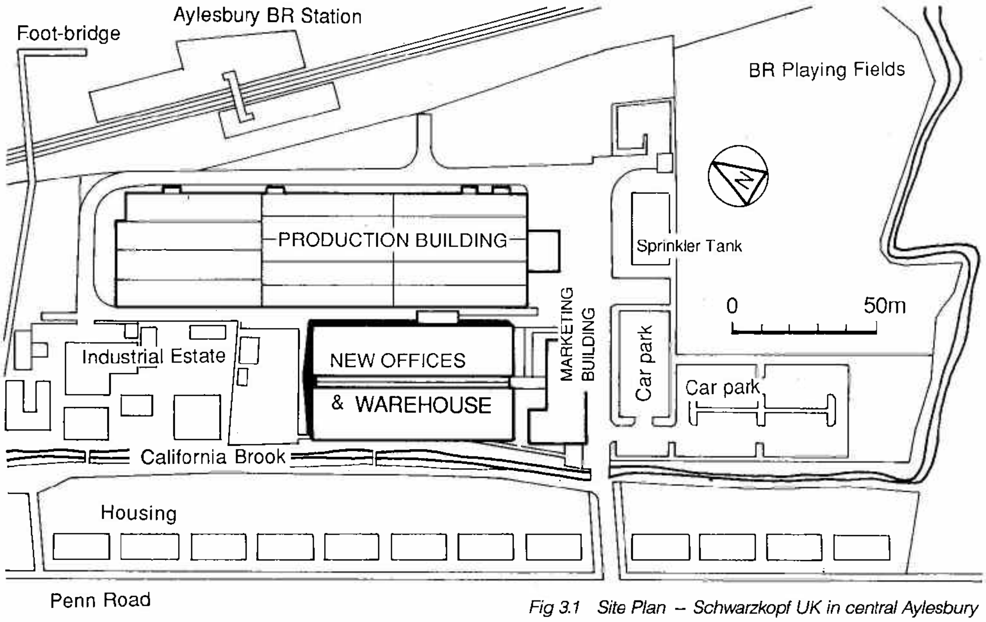


Fig 3.1 Site Plan – Schwarzkopf UK in central Aylesbury

Design limitations

The site access was restricted to a small bridge over the stream on the southern boundary facing onto a housing estate (Fig 3.1). This limited access meant that, as business developed, there was a rapid increase in the number of lorries and employees' cars flowing through the housing estate. Schwarzkopf urgently wished to improve this situation by the construction of a 300m road on adjacent land designated for a town centre bypass. After several studies and the purchase of property for access, the road proposal had to be abandoned when the local authority not only wanted Schwarzkopf to pay for the road construction but also to purchase the land. Economically the client had no option but to revert to improving the bridge over the stream.

The office and warehouse faced across the stream into the back gardens of the council houses, and consequently planning approval for warehouse facilities hinged on the provision of an attractive view for residents. The conventional "tin box" style for industrial buildings was therefore eliminated at an early stage. The design finally adopted by Denton Scott Associates consisted of a shallow pitched roof with deep overhanging eaves and a central roof light. The external cladding is predominantly concrete blockwork with contrasting brick bands, large glazed areas differentiating the offices (Fig 3.2). This had the desired effect of improving Schwarzkopf's image whilst providing an attractive elevation for local residents.

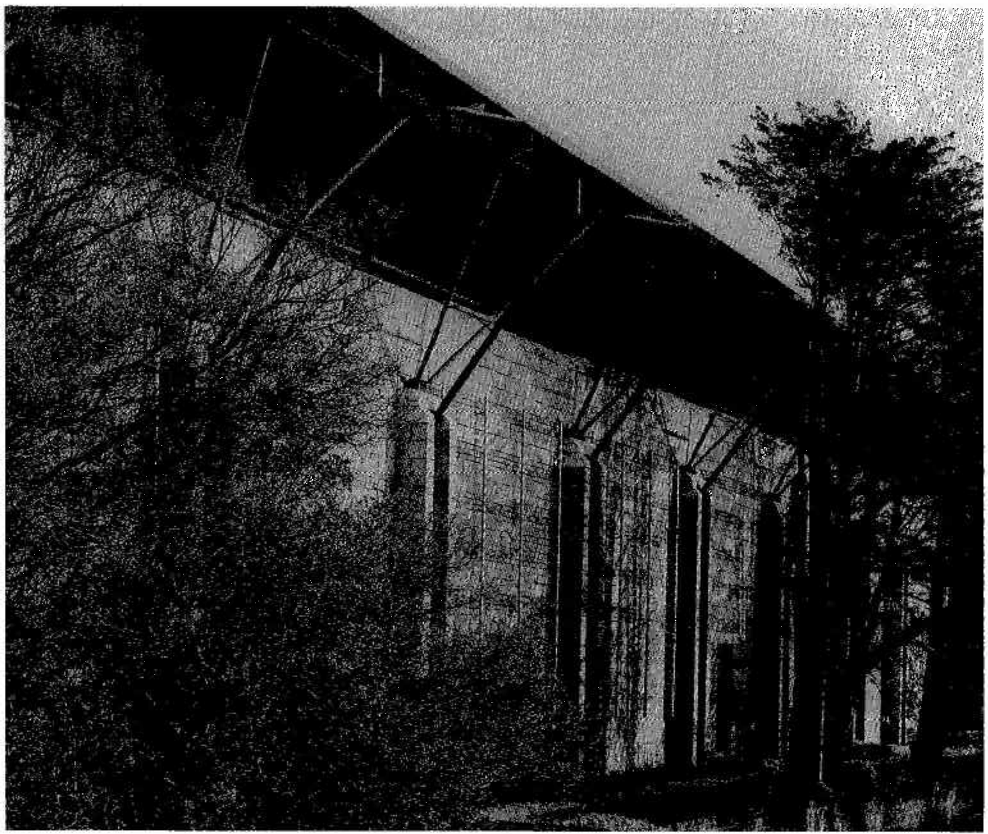


Fig 3.2 External elevation showing warehouse cladding and eaves detail

Site and soil constraints

The site lies between two streams and consequently consists of a 2.5m alluvium flood plain, overlying stiff

Kimmeridge Clay. The water table is often within 600mm of ground level. Furthermore the stream is prone to flooding and the local river authority required that the run off from the roofs and paved areas should be delayed by means of a storm water retention scheme. This was achieved by surrounding the warehouse building with 600mm diameter pipes which throttled down to a 225mm diameter outlet into the stream, so ensuring that discharge during any given period did not exceed that occurring prior to the new development.

The internal column loads for the two storey office and warehouse were 570 kN and 160 kN respectively. The depth to the clay was within the range of a mechanical digger thus, providing the contractor could deal with the problem of the high water table, mass concrete pads were a viable foundation solution. In the event this work was carried out with little difficulty.

The high water table also meant that special design precautions had to be taken to prevent rising damp and the recommendations of CP102 'Protection of buildings against water from the ground' were adopted. This consisted of 150mm of type 2 aggregate blinded with 50mm of 1 : 6 concrete, trowelled smooth and then sealed with two coats of cold bitumen solution with a thickness of 0.6mm, topped by a 200mm mesh reinforced slab.

Warehouse layout

The warehouse is the storage facility for both products manufactured on site and those imported from Schwarzkopf's European factories. These are then selected by a picking and packing process to make up the orders for delivery to wholesalers in the hairdressing trade. The warehouse holds 1900 pallets in five level racking, and requires a 7.3m clearance to the soffit of the roof steelwork. The 54m long warehouse is divided into 10 bays with an aisle for forklift trucks between the racking. The overall width was 34.2m, with the main aisle and access doors to the north wall which faces across a connecting road to the production unit (Fig 3.3).

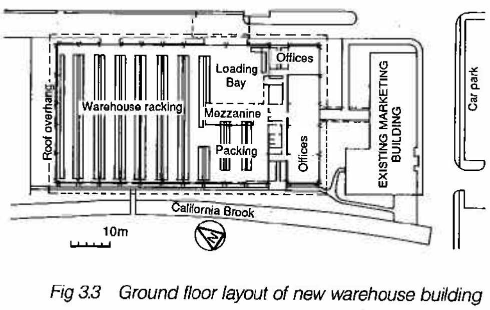


Fig 3.3 Ground floor layout of new warehouse building

The client held preliminary discussions with racking manufacturers but an appointment was delayed until the end of the contract period. This was unfortunate as it meant that the ground slab joints had to be positioned without knowledge of the exact location of the racking point loads.

The average load was known but this could not reproduce the pattern of bending movements which result from the individual stanchion loads. In particular it is essential to know if a heavily loaded stanchion sits on the corner or edge of a concrete panel. In an attempt to overcome this difficulty details of the construction joints and floor design were included as part of the tender packages sent to the racking manufacturers.

Unfortunately, they appeared to have no comprehension of the significance of the joints in relation to the stanchions, clearly as far as they were concerned it was somebody else's problem. In the end, by careful back checking, it was possible to prove that the racking layout was acceptable. In this instance a solution was possible, but as warehouse floor loads become heavier we strongly advocate that the racking layout should be determined by the client or his specialist and this should be part of the design brief given to the engineers.

Warehouse slab design and construction

The design of the warehouse slab was based on the long strip method with an expansion joint at the halfway point, resulting in 27m long bays with transverse joint at 5.4m centres. The width of the bays was set at 4.5m, which avoids the need for cutting standard 2.4m wide mesh reinforcement, by using a 200mm lap between the sheet sides. This also provided a manageable width for tamping and finishing.

The slab design was based on the method given by C & CA (Ref 3.1) which resulted in a 200mm 40 N/mm² concrete slab reinforced with C283 mesh placed 50mm from the surface. The mesh was maintained in position using proprietary linear triangular chairs. High reach fork lift trucks require a level, smooth, dense floor surface. The client requested a tolerance of ± 3mm in 3m, which was achieved by power floating, followed by power trowelling.

From the side rails of the long strip bays the contractor proposed the Permaban system of precast concrete rails (Fig 3.4) which are permanently left in position. This has the advantage of preventing damage to the slab edge which can occur when striking conventional steel forms. It also reduces the risk of lipping, as the precast units can be accurately levelled on mortar bed, prior to concreting. In some locations slight shrinkage cracks opened up parallel to the units, but in general it would be beneficial to specify this or similar methods for future industrial projects.

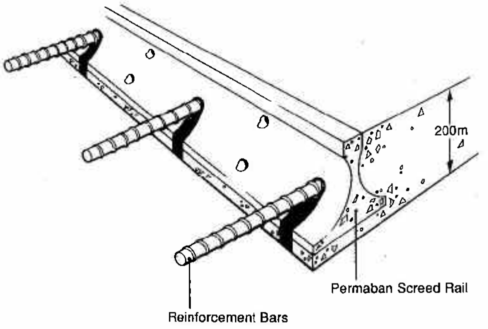


Fig 3.4 Detail of Permaban precast rails for slab

The transverse joints at 5.4m centres were saw cut a few days after concreting and then sealed with cold poured bitumen. Saw cutting is preferable to forming these joints with plastic strips left in position which tend to float in the wet concrete. Even if they are only 1mm proud of the concrete surface they will break under the impact of fork lift trucks. The alternative of removable metal strips should not be used as it is difficult to power float alongside these. During removal there is a possibility of damage to the slab edges and quite often there will be a slight difference in level which again breaks down under the impact of the hard rubber wheels of fork lift trucks.

Reinforced masonry

In order to avoid the tin box image for this development, the architect developed a very attractive masonry scheme using a combination of Forticrete Bath stone coloured blocks with a band of Forticrete terracotta coloured bricks every third course.

The masonry wall was 6.3m high, restrained at the top by a 203 × 203UC with projecting straps at 450mm centres and with sliding wall ties to transmit wind loads back into the steel frame (Fig 3.5). The wall consists of hollow 215mm outer and 100mm inner skins of blockwork with a 50mm cavity. On the side elevations the wind load is distributed between the piers at 5.4m centres and the floor (Fig 3.6). Due to its high shrinkage Forticrete requires frequent movement joints. The double piers provided an excellent opportunity to conceal these 10mm movement joints in the 460mm wide recess between the piers. The masonry was capable of spanning 5.0m between the piers but on the gable walls where the pier spacing was 6.8m, stainless steel reinforcement was required in alternate courses of the 215mm outer skin.

The piers themselves were designed as propped cantilevers, using hollow concrete blocks with a

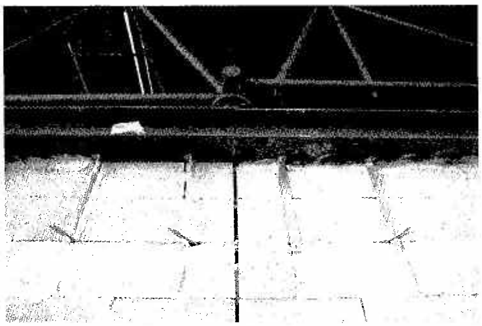


Fig 3.5 Restraining straps and UC at top of masonry wall

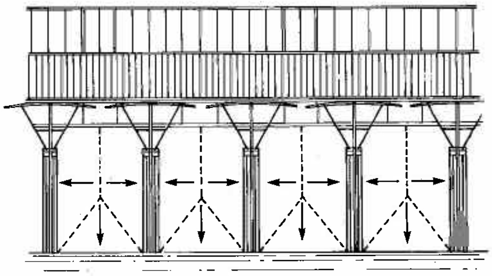


Fig 3.6 Wind load distribution on masonry – side wall of warehouse building

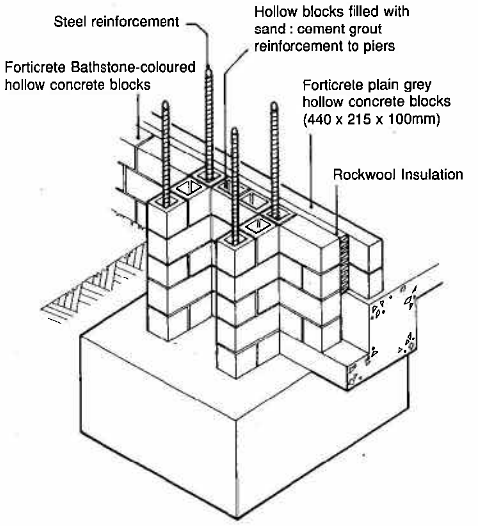


Fig 3.7 Reinforcement bars within masonry piers

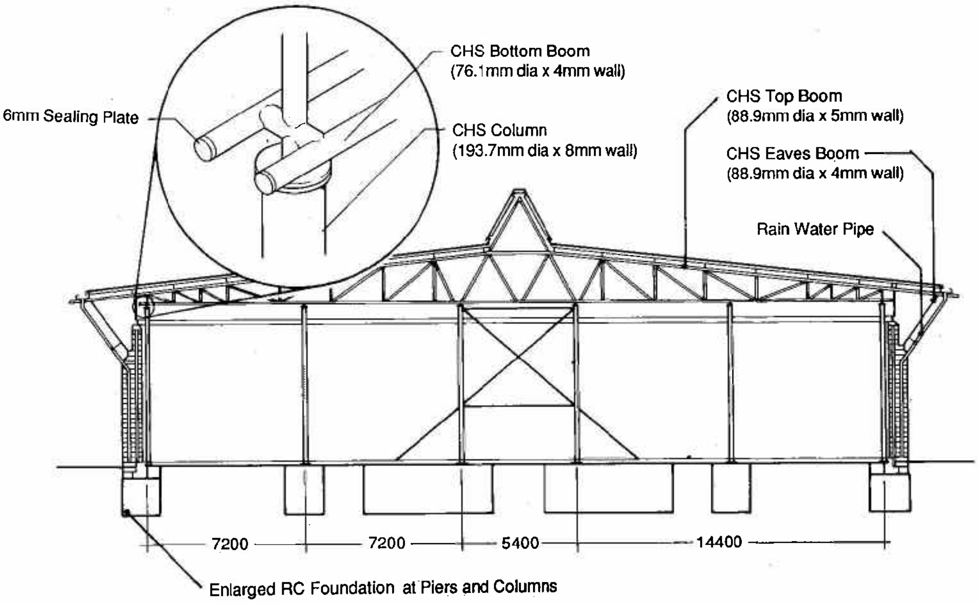


Fig 3.8 Section through warehouse truss span with pedestal and flange detail of truss/column connection

20mm bar placed in each void and then grouted as the work proceeded (Fig 3.7). The difficulty with reinforced masonry is that unlike reinforced concrete the reinforcement cannot easily be fixed as single full height bars. Any reinforcement has to be detailed in short lengths so that succeeding blocks can be threaded over the top without too much lifting. Without a clerk of works this type of detailing places reliance on the contractor to ensure that the correct laps are obtained and that the grouting is properly carried out.

For the future we would adopt a detail where the reinforcement can be erected as a single length. Either the piers should be built in brickwork with a recess to enclose the reinforcement, or one face of the blockwork should be cut to allow insertion of the reinforcement. However, either way it would not be possible to achieve the slender piers adopted at Schwarzkopf.

Structural steelwork

The design evolution of the warehouse, and of the roof in particular, is an interesting example of the interdependence of architect and engineer. To an engineer, structural efficiency is measured in terms of stress levels, weight, materials and constructability – whilst for the architect the considerations are primarily those of aesthetics and harmony of design within a cost constraint.

It was agreed early on that portal frames were an inappropriate solution and that trusses were preferred with regard to the span, the triangular roof light form and the need for a level soffit to accommodate the racking. The spacing of the trusses was dictated by the layout of pallet racking and access. Transverse frames evolved as main trusses with a span of 14.4m and a central bay of 5.4m which was developed by the architect as an isosceles triangle to provide light and ventilation (Fig 3.8).

The initial idea was to use rectangular hollow sections for the 14.4m trusses for ease of fabrication, requiring a single cut to shape member ends. The architect preferred circular hollow sections as these reduced the visual obstruction and were more in keeping with the pin joint philosophy he wished to adopt. It was appreciated that profiled cutting would be required to join the tubes but this was a relatively minor consideration. The architects were also keen to ensure that the lighting, heating and sprinklers should be consciously integrated with the roof steelwork. This appeared to be an admirable and relatively simple task. The design team proposed an elegant idea where the truss was designed as a single top chord with bracing members but with the bottom chord as a pair of tubes spaced 300mm apart. The truss was to be located immediately above the back to back racking and it seemed logical that the sprinkler pipe should be nested neatly between the chords as this would facilitate the vertical drop between the racks.

However the sprinkler installers have immense freedom – they are more than sub-contractors, they also certify the work which means that unless it is carried out to their layout, it is impossible for the owner to obtain fire insurance cover. Their interpretation of the F.O.C. rules was that the sprinkler pipe had to be offset from the truss and no amount of discussion could persuade them otherwise.

The moral would appear to be that if sprinkler layouts are to be co-ordinated with the structural layout, then a sympathetic nominated contractor must be appointed well in advance of the main contractor to ensure that the design intention can be achieved.

Further design problems

During the preliminary stages of the design several decisions were made where the full consequences did not become apparent until the detailed design stage. It was agreed that the building should rely on pin connections between the columns and trusses, and between the components which made up the central triangular spine truss.

The completed triangular spine had an overall height of 4.67m with a base width of 5.4m and unit lengths of 10.8m. Obviously a unit of this size was too large to be brought to the site by road and thus a series of 3 sub triangles were fabricated with pin connections. These pin jointed trusses also provided wind bracing, which meant that close tolerance bolting had to be adopted to eliminate any slack in the system.

On the main truss the connection between the truss and the column was a pedestal and flange detail (Fig 3.8) which worked very well. At the inner ends the truss is supported by the central triangular trusses which are in turn pin connected to the columns. As the triangular trusses shared a single column it was not possible to repeat the pedestal detail and it was necessary to provide overlapping plates onto a single pin (Fig 3.9). The problem with such a detail is that the line of action of the forces is no longer concentric and therefore bending occurred on the minor axis of the pin hole plate. Furthermore the tubes connected to this plate were only 139mm diameter so that the opportunity of providing weld and stiffness was severely limited. Only by finite element analysis was a complete redesign of the detail avoided.

With a high bay warehouse the overriding design factor is one of stability and the control of sidesway. In this instance the height to the eaves was 7.8m and the limiting sway was established as height/200, at 40mm. The warehouse and office block were treated as independent structures even though they shared a common roof structure. Stabilisation of the office block was a relatively simple matter of using the 7.2m grid of composite construction at 1st floor level to transfer forces to the braced frames.

The transmission path of transverse wind forces to the ground via the central horizontal girder to the bracing at each end of the warehouse building are shown on Fig 3.10. Whilst the central bracing could be designed to resist the stress imposed, its length/breadth ratio of 10 was insufficient to satisfy the sway criteria over the central section. This could have been achieved by increasing the member and connection sizes but would have been uneconomic. The alternative was to mobilize the complete roof as

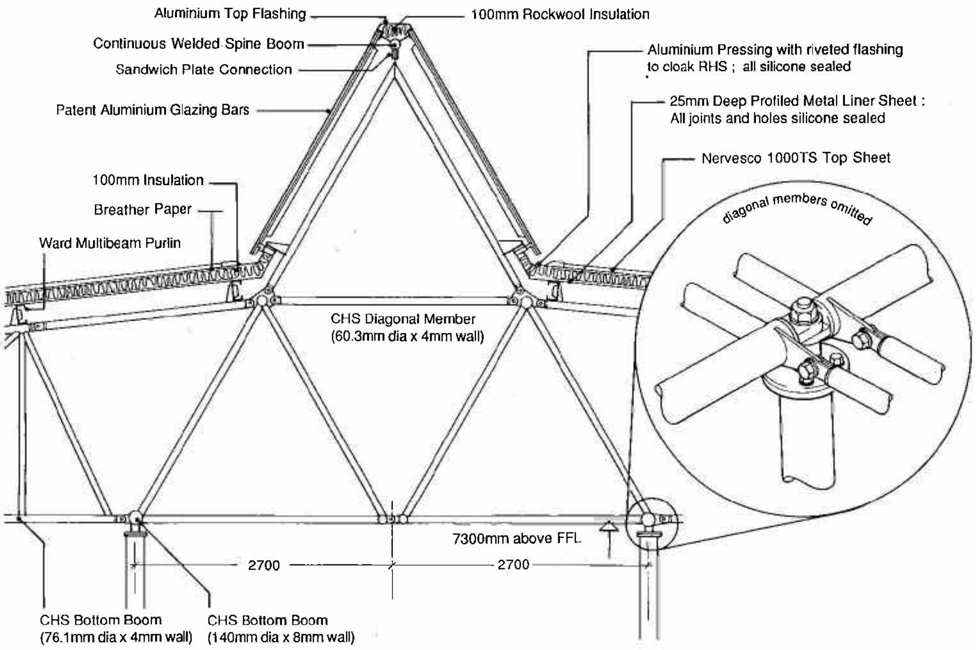
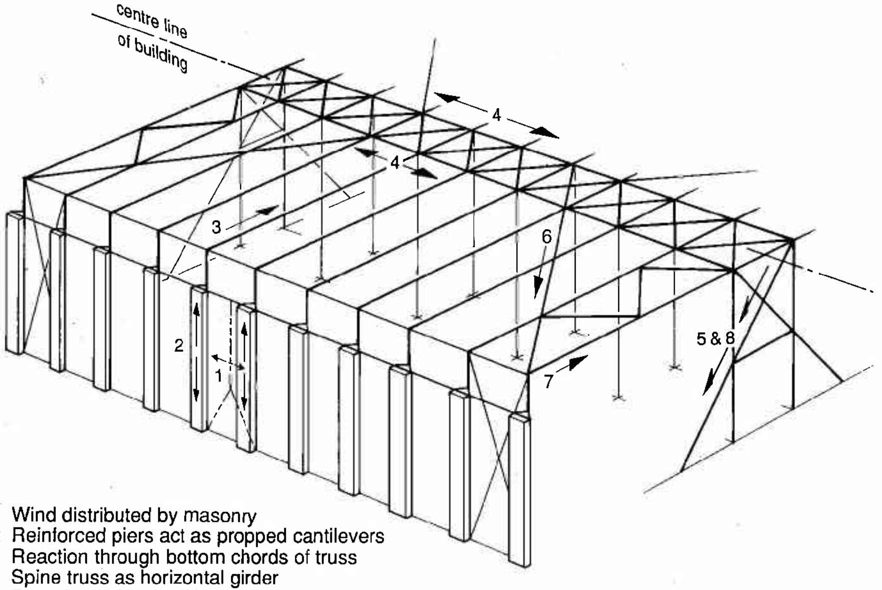


Fig 3.9 Detail of pin and plate connection of central triangular truss

Fig 3.10 Transverse wind load distribution to end of warehouse building



1 Wind distributed by masonry
2 Reinforced piers act as propped cantilevers
3 Reaction through bottom chords of truss
4 Spine truss as horizontal girder
5 Part of reaction transformed to ground by vertical bracing
6 To increase transverse stiffness, roof ties are provided
7 Reaction through gable end truss
8 Force transformed to vertical bracing

a partial truss. This latter system was achieved by providing ties between the corner of the building and ⅓ points of the wind girder. The longitudinal wind loads were resisted by a horizontal girder at each end of the warehouse which distributed the outer edge, and then by vertical bracing to the ground.

A further important feature of the design was the 2m projection of the eaves beyond the wall line. A continuation of the truss was not acceptable as a roof support as visually this was too strong an element, destroying the image of the roof floating over the brickwork. The solution used a wish-bone frame propped from the masonry pier (Fig 3.11). A structural gutter was required to support the roof sheeting, and the wish-bone had the benefit of reducing the span of the gutter beams. Even so, structural gutters are never an efficient form as the compression flanges are minimal and have no effective lateral restraint. This form of construction is unpopular with fabricators as gutters are traditionally part of the roof cladding. Furthermore the architects always appear to be disappointed at the weight and thickness of metal required for such gutters. In spite of achieving a 4mm plate thickness, with the width of gutter required for this project the weight of each 5.4m length of guttering still exceeds 200 kilograms. With hindsight it would have been preferable for the gutter to have been non-loadbearing, supported by a pair of rectangular hollow sections. However it has been agreed that the eaves details do provide a most dramatic effect which overcomes the rather weak eaves line characteristic of many of our industrial buildings.

The completed Schwarzkopf warehouse has received considerable favourable comment in the technical press. It is a style and form which we expect to develop further in new projects with Denton Scott Associates, notably the competition winning design for Aston University.

John Morrison

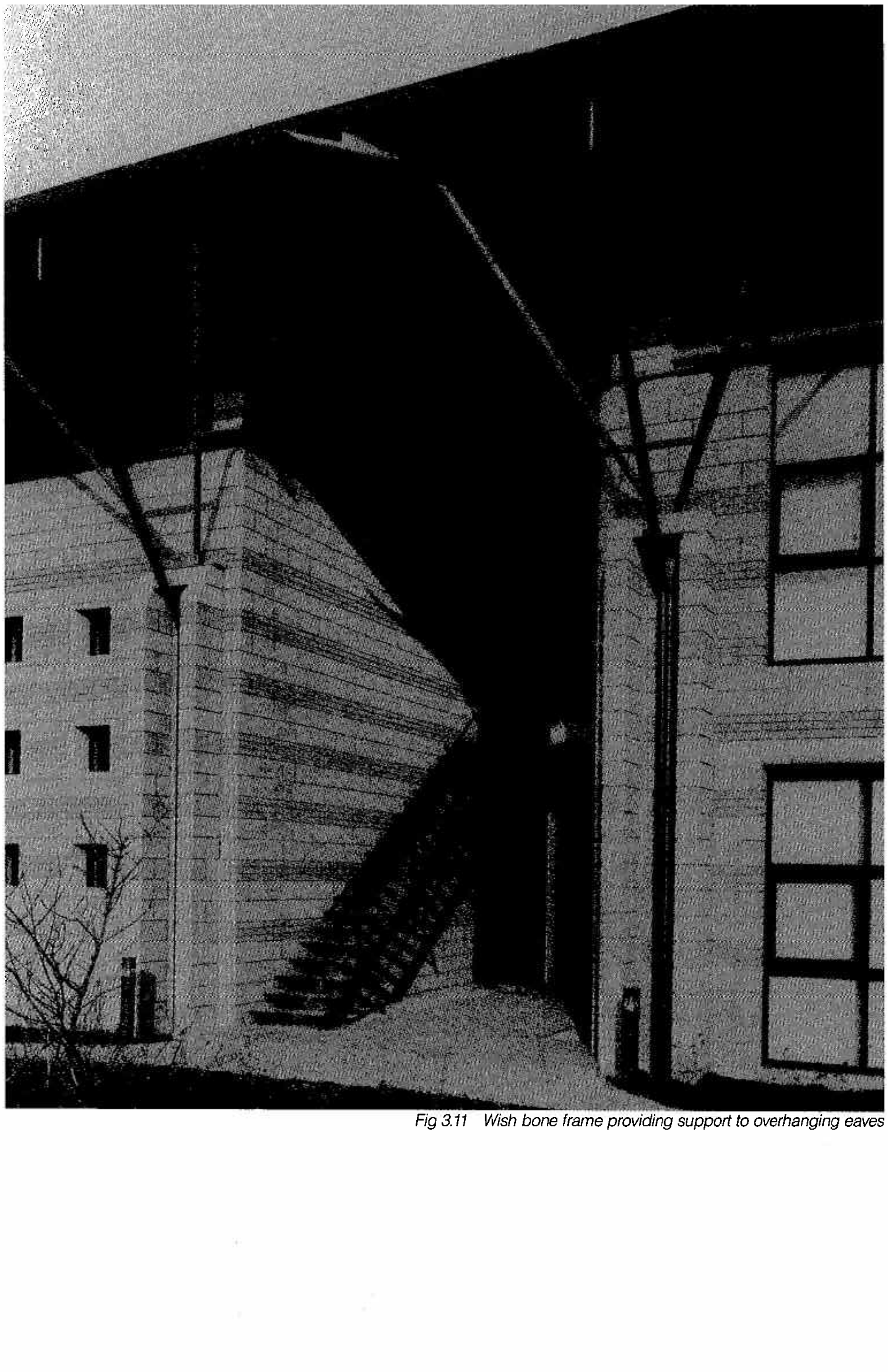


Fig 3.11 Wish bone frame providing support to overhanging eaves

References

3.1 Deacon R.C. 'Concrete Ground Floors – their design, construction and finish'. Cement and Concrete Assoc, 1986.

Infrastructure and Highway Design for Emerson's Green Science Research Park, Avon

Project data

Client	Emerson's Green Development Company
Architect	Renton Howard Wood Levin
Civil Engineers	Buro Happold
Traffic Engineers	Transportation Planning Associates
Environmental Consultants	ERL
Economic Planning Consultants	Roger Tym and Partners
Valuation Surveyors	Jones Lang Wootton
Site Area	550 acres
Civil Eng. Infrastructure Costs	£24m (estimated June 1989)

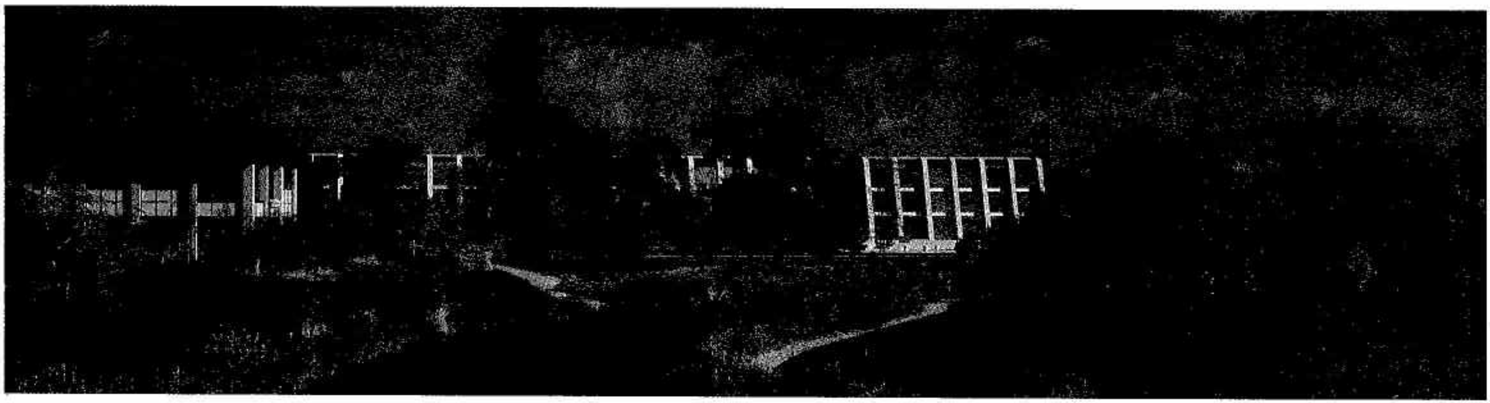


Fig 4.1 View across lake at Cambridge Science Park (photo courtesy Bidwells)

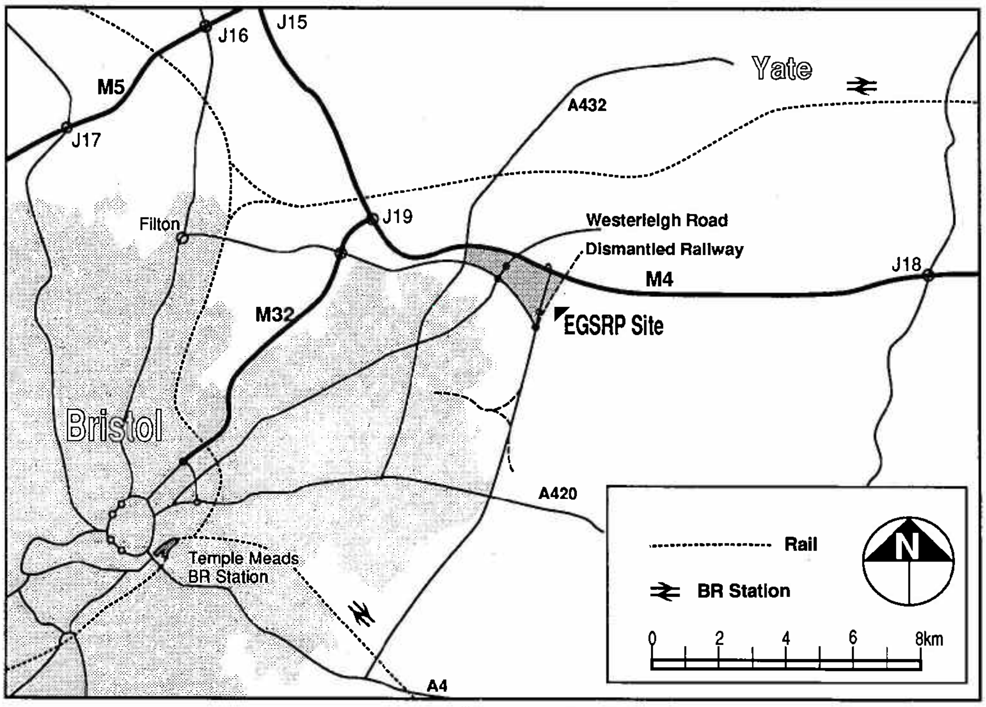


Fig 4.2 Location plan of Emerson's Green Science Research Park

The concept of the science research park is to provide an environment where technological research and development by both academia and industry can proceed closely together, providing an interface between university teaching and research work, and the development of a product or process. The speedy transition of an idea into technical and commercial reality is thus better assured.

Science parks are already in operation, the most notable being in North Carolina, USA, Nice in France, and at Hsinchu in Taiwan. In the UK the most well known example is at Cambridge (Fig 4.1), although another at Warrington, and innovation centres at Warwick and Bradford are operational.

A new research park?

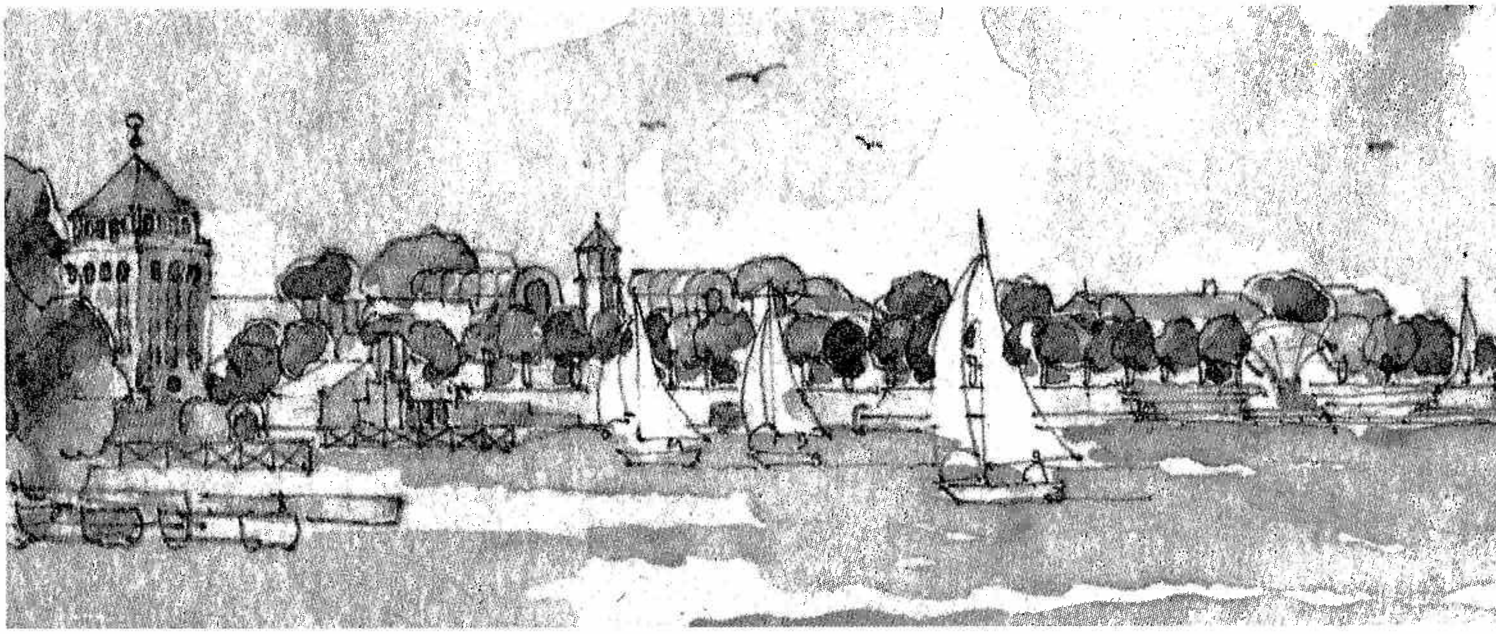
The proposed science research park at Emerson's Green (EGSRP) combines the academic institutions of the Universities of Bath and Bristol, and Bristol Polytechnic, with development being promoted by Chesterfield Properties and the Merchant Bank, Hambro Lisandro. The Emerson's Green Development Company has been formed between these parties and their objective is to provide a park with a research-based foundation at the heart, providing an opportunity for industries to develop out of innovative work carried out within the foundation. This foundation will ultimately accommodate 150 research staff at post graduate level and above, and will include laboratories, residential accommodation, sports facilities and small industrial starter units.

Around this academic heart various campus-style developments of varying sizes and styles will be engaged in technological research and production work, often using the resources of the foundation centre in their activities. The surrounding campus units themselves will total at least some 3.25m ft², and will allow a variety of developments varying between 2 and 25 acres. The EGSRP proposal also includes the construction of a 200 bed hotel with conference facilities, and a development of 350 residential units on various parts of the site.

The true heart of the project will however, be the academic centre and its associated facilities, and these buildings will be planned in relation to a new village green and man made lake. The proposals, furthermore, call for a low density of development and provision of extensive landscaping to enhance the environment.

Site location and planning issues

The Emerson's Green development area is located on the north east fringe of Bristol, falling within the jurisdiction of Northavon District Council and Kingswood Borough Council (Fig 4.2). The area was released from green belt for development in 1986 by the Secretary of State for the Environment. The northern boundary is defined by the M4 motorway, the eastern boundary by the disused Bristol to Yate railway line and to the west limited by the residential areas of Mangotsfield and Blackhorse (Fig 4.3). A section of the proposed Avon Ring Road will run through the site in a north west to south east direction, and the science park is located between this road and the M4 motorway, on a site of



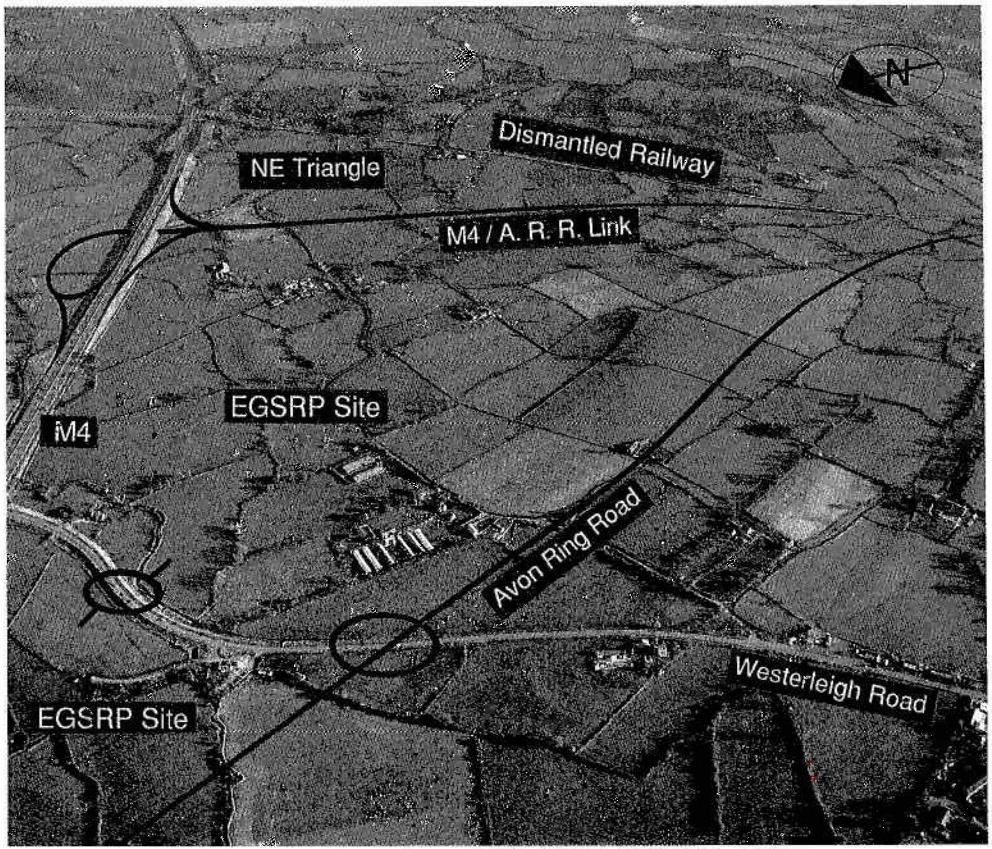


Fig 4.3 *Aerial view of site showing planned development (from W)*

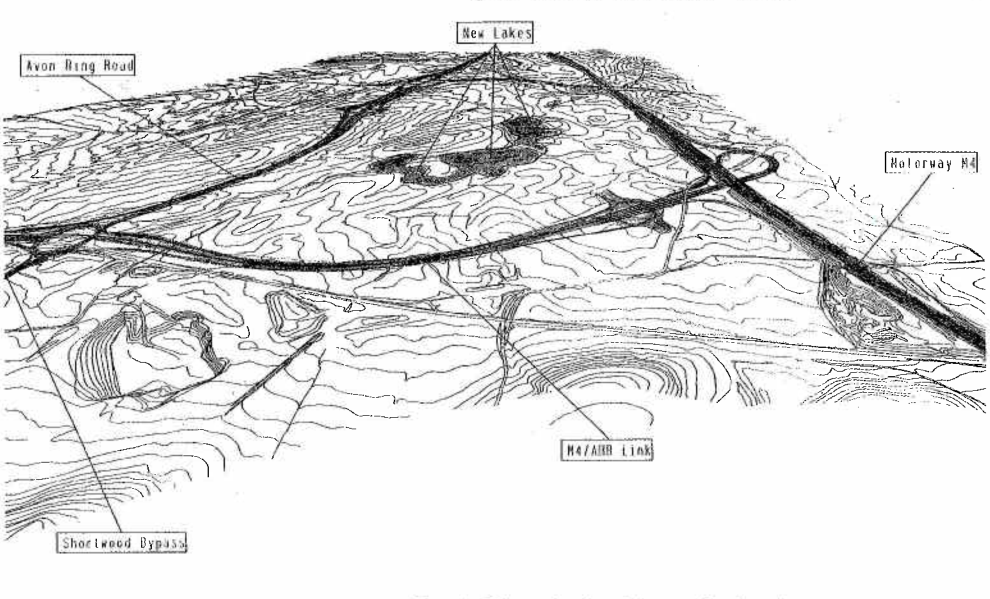


Fig 4.4 *Schematic view of site from E, with main communication network*

approximately 550 acres (Fig 4.4). Extensive housing development is planned south of the ring road.

An alternative proposal exists for the site, made by a group of land owners who have suggested a retail development in combination with a reduced science park, and including other business and commercial uses. The concept for a science park, and for the land uses the layout proposed by the Emerson's Green Development Company, have however, been adopted by both local authorities in their draft local plan documents (Fig 4.5a,b). These two plans were the subject of inquiries during the summer of 1989, concurrent with the planning appeal inquiry for the proposed alternative retail development, since this had been refused planning consent by the two local authorities. The outcome of the inquiries is expected to be announced in mid 1990.

Site geology

A preliminary assessment of the geology of the site has been carried out so that initial recommendations for engineering solutions could be made. Hydrogeological aspects have also been investigated on a preliminary basis in relation to the construction and impoundment of the lakes.

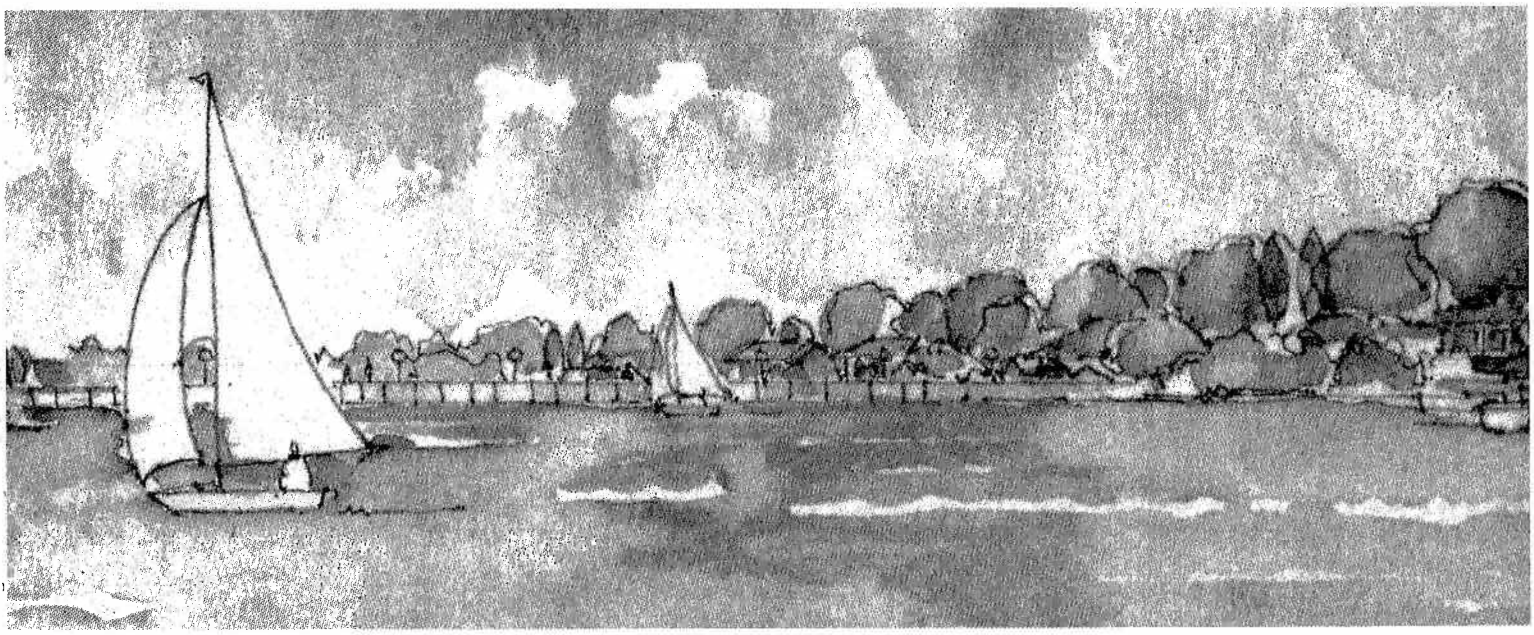
The site is underlain by folded and faulted rocks of the Pennant series and the Upper Coal Series of the Upper Coal Measures, overlain by a partial thin layer of Keuper Marl. In the north eastern corner of the site there is a variable cover of alluvium, which is predominantly soft to firm blue brown clay.

Previous mining activity to the east of the site, which ceased in 1906, is not expected to present any problem as the worked seams lie at a depth of 150m. As the workings are overlain by competent rocks it is unlikely that there will be subsidence. However, shafts will need to be located and stabilisation undertaken where they are encountered. The extent of shallow workings on other parts of the site, particularly under the proposed line of the Avon Ring Road in the west, will require investigation by trenching, and treatment where necessary.

Generally, spread foundations should be adequate for all light structures once allowance has been made for any shallow coal workings. Bridges at the Avon Ring Road/M4 interchange may straddle a geological fault, and solutions may require piled foundations and a design permitting differential movement. Some piled foundations may be required elsewhere, but this will be established as part of an extensive site investigation.

Civil engineering infrastructure

Such a large scale development area obviously requires a considerable civil engineering infrastructure, with the highway network the most



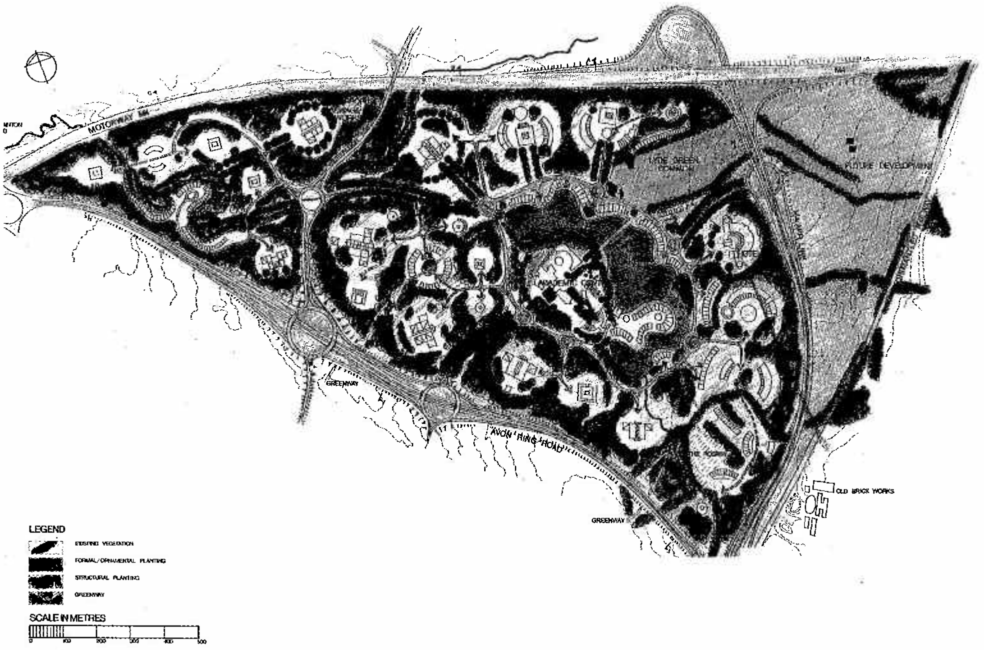
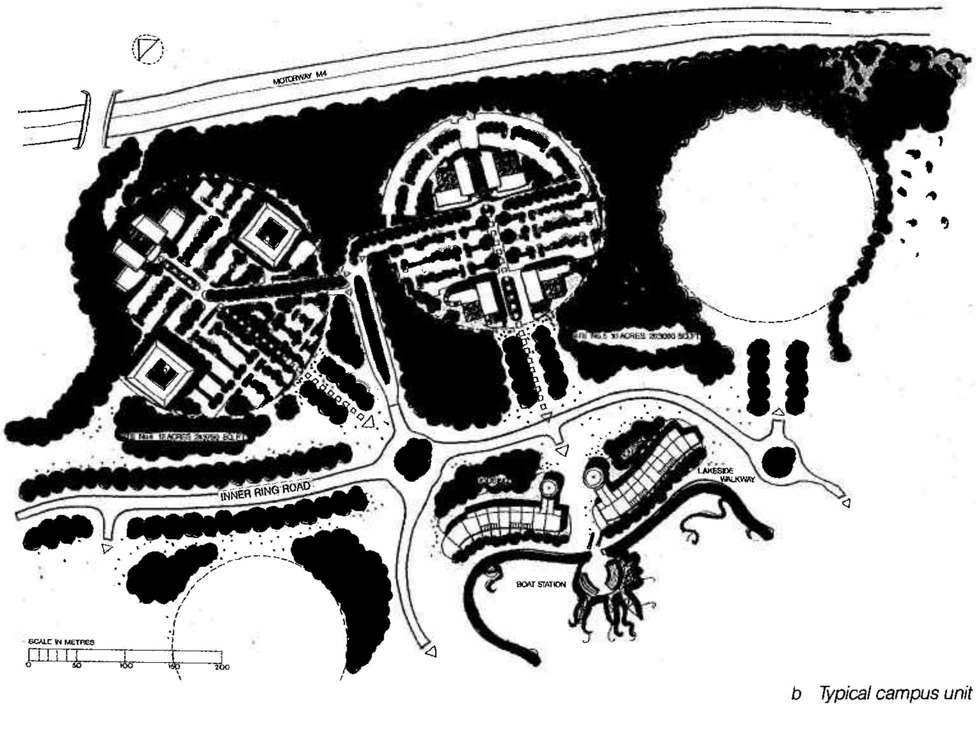


Fig 4.5a EGSRP landscape plan



b Typical campus unit

significant component. Extensive proposals have therefore been developed to service the EGSRP development in this respect.

The Avon Ring Road provides an orbital route around the northern and eastern edges of Bristol linking the M32 to the A4 Bristol-Bath road. Stages 1B(i) and 1B(ii) of the Avon Ring Road pass through the Emerson's Green development area, separating the science research park from the housing area to the south. A new dual carriageway link between the Avon Ring Road and the M4 motorway, originally planned by Avon County Council as the highway authority, will be located and aligned to optimise land use and access provision to the development site. Access to the science park will be gained from this link road, from the Avon Ring Road itself, and on the west side from Westerleigh Road (Fig 4.6).

The peak hour traffic flows generated from the proposed science park, together with the housing area traffic, has been determined and agreed with the highway authority and added to the base traffic predicted on the highway network. These base traffic levels have been estimated using the increased traffic high growth forecasts, published by the Department of Transport in June 1989, (Fig 4.7) which indicate a likely increase in total traffic flow from 1988 to 2025 of between 83% and 142%. Junction layouts have been developed to assure adequate capacity during these predicted peak hour flows and tested using the Arcady computer program. This work has indicated the need for grade separation for the major traffic movements in several cases. Highway links, junction geometry and bridge designs have consequently been developed in preliminary form to establish their feasibility, and in progressing these designs reference has been made to TD22/86 – Layout of Grade Separated Junctions and TD9/81 – Highway Link Design published by the Department of Transport (Refs 4.1, 4.2).

At the intersection between the link road and the motorway, the Department of Transport require a "free flow" junction. This has been proposed as a "trumpet" interchange with new underbridges passing beneath the M4 (Fig 4.8). In-principle approval has been received from the Department of Transport to the design, and an outline construction method has been developed to demonstrate how work may proceed on the junction while keeping the motorway open, with three lanes operational in each direction.

Drainage considerations

The surface water drainage regime of the site will be centred on the new lake and the Folly Brook tributary which runs through the area. The development lies within the overall catchment of the River Frome, and the National Rivers Authority, in recognition of the

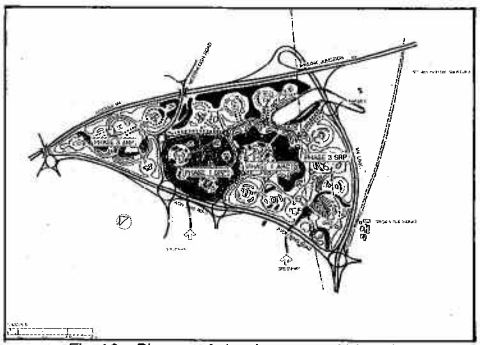


Fig 4.6 Phases of development within science park

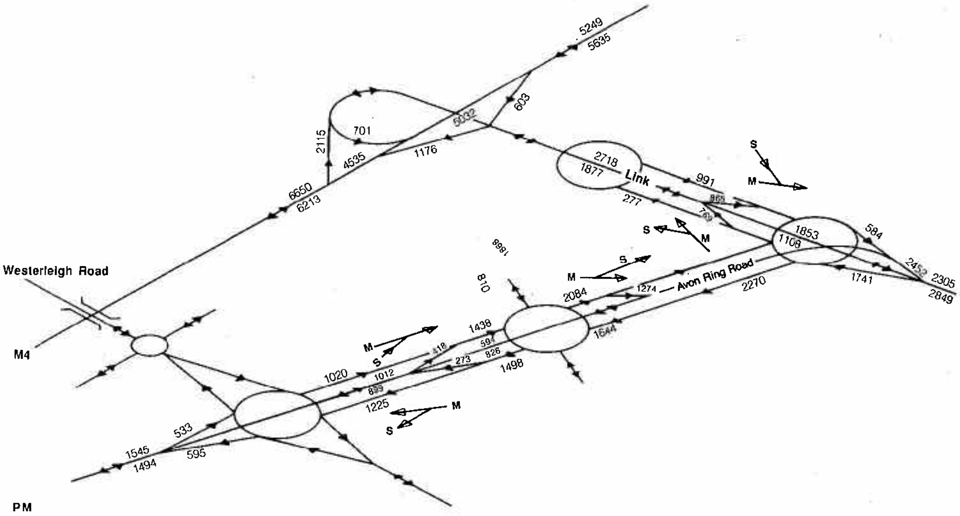
effect such a large development may have on land drainage, intend to carry out a flood study over the whole of the Frome catchment area to establish whether detention ponds or stream improvements will be required at Emerson's Green, or indeed elsewhere.

Present indications are that the new lake will act partly as detention for the eastern part of the science research park, with other attenuation areas required in the north western sector (Fig 4.9). A preliminary evaluation based on the NERC 1975 Flood Studies Report (Ref 4.3) suggests that a volume of 270,000m^3 of storm water storage generated by a 1 in 140 year storm, must be detained on the site, and this requirement has been incorporated within the Master Plan.

There are no public sewers immediately adjacent to the development area, and foul water drainage will outfall westward towards the Frome Valley trunk sewer which runs alongside the River Frome approximately 1.5 km from the site. This trunk sewer does not at present have spare capacity to receive the Emerson's Green discharge, but sufficient capacity will be made available in the sewer when the northern Frome Valley relief sewer is constructed, relieving the existing sewer of a proportion of its present flow. Wessex Water intend that the developers at Emerson's Green will make financial contributions to the new trunk relief sewer, allowing this capacity to be made available to them. These considerations are now a matter of continuing discussion.

As an alternative, proposals are being developed to provide an on-site treatment works to treat effluent to the appropriate standard, and discharge it westwards to the River Frome itself (Fig 4.10). The standards and operating equipment in the works are being established in discussion with Wessex Water and the National Rivers Authority (NRA) to achieve an effluent discharge satisfying the requirements necessary to obtain consents under the terms of the Land Drainage and Control of Pollution Acts.

Fig 4.7 Estimated peak hour (pm) traffic flows through EGSRP road network



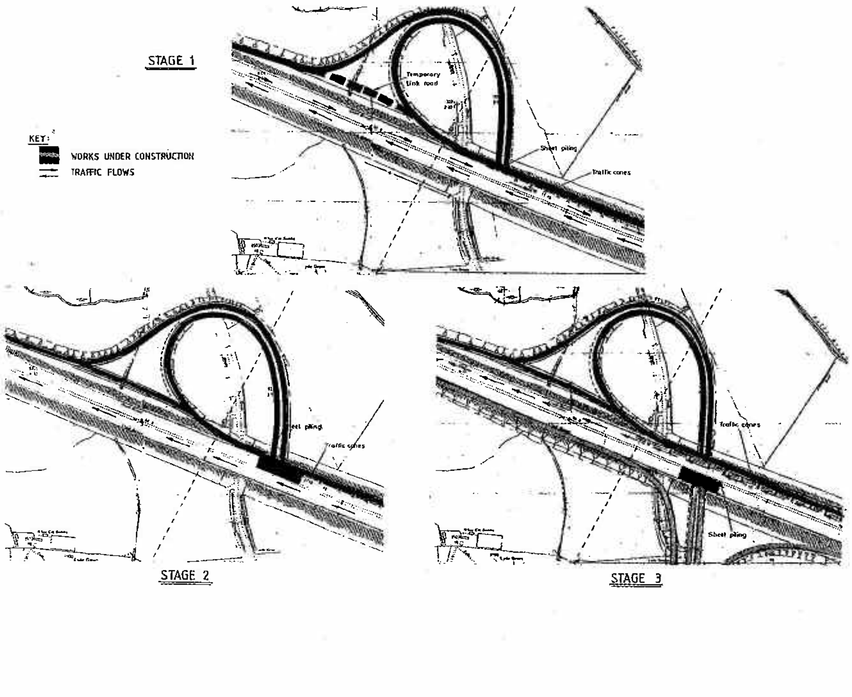


Fig 4.8 Phases of construction of "trumpet" interchange

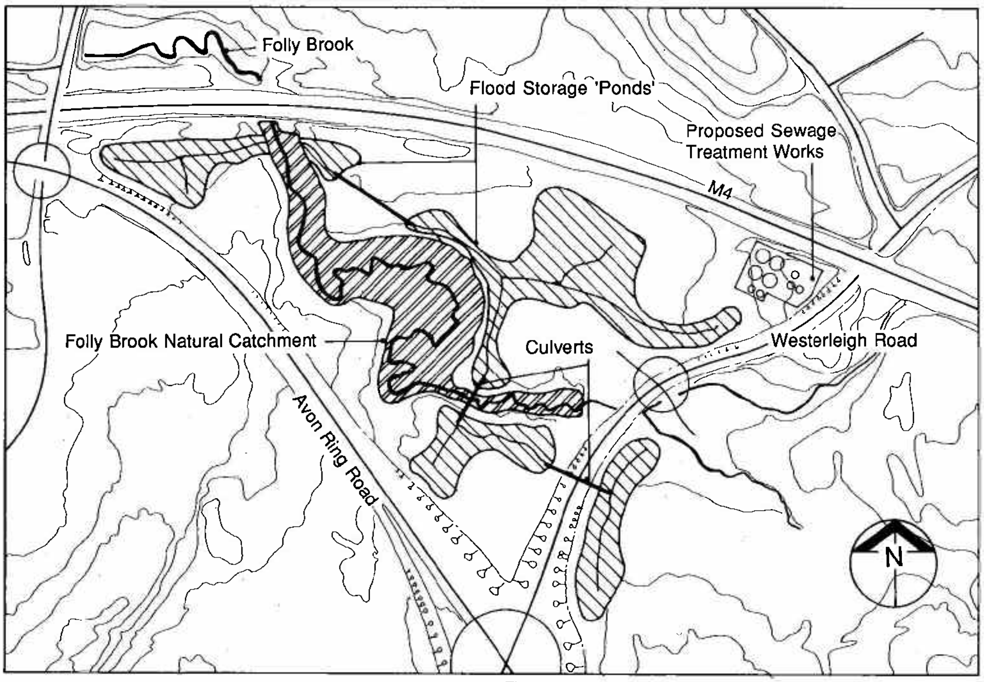


Fig 4.9 Proposed surface water attenuation for development

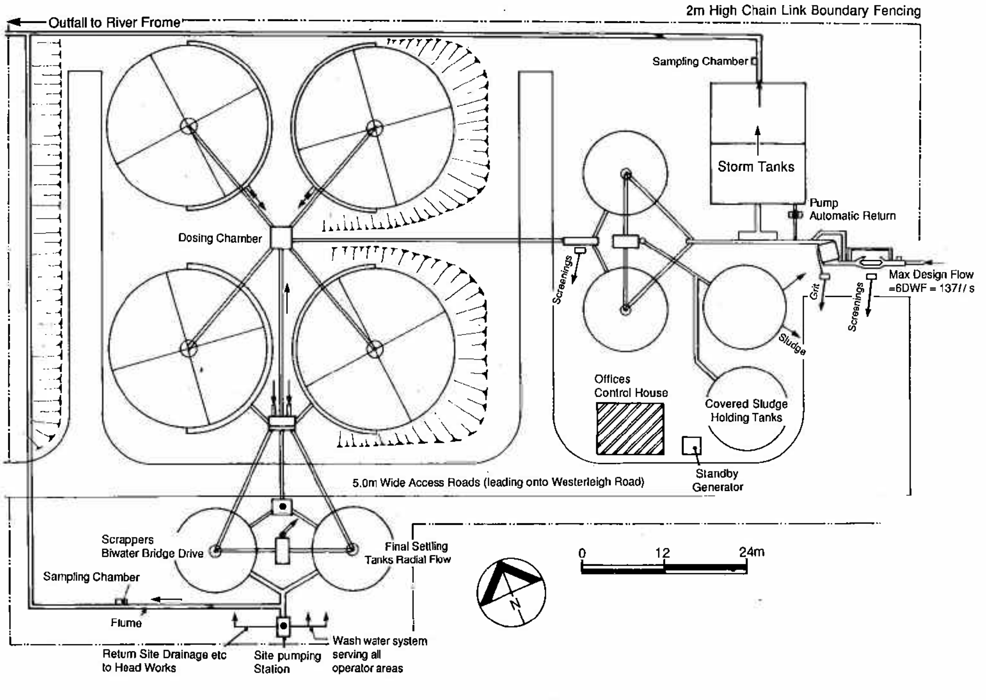


Fig 4.10 Filter plant layout for on-site sewage treatment works

At present three lakes are proposed and these form an integral part of the scheme offering the benefit of stormwater attenuation and recreational use. Their relationship to the surface water drainage system and existing watercourse will need to be carefully assessed, in order to maintain the present normal flows downstream of the site and to ensure a satisfactory performance with regard to their intended use. It is proposed to carry out a flow-gauging exercise to identify these constraints.

The lakes cover an area of approximately ten hectares and will impound a volume of water of the order of 200,000m³. It is likely that 25,000m³ or more will be stored above surrounding ground levels and therefore come under the Reservoirs (Safety Provisions) Act 1975. They are to be constructed generally within the Keuper Marl, a relatively impervious material, but some leakage is likely to occur and preliminary investigations have been made with regard to the initial filling, and to the augmentation of water supply to the lakes, by means of a borehole supply.

Discussions have taken place and principles agreed with Wessex Rivers in respect of the procedures required to obtain a licence for the abstraction of water from underground strata under the Water Resources Act 1963, and for the test borehole and field study.

From a preliminary study of the area and known existing abstractions it is considered that sufficient water will be available from underground strata to fill the lakes and maintain levels during periods of drought.

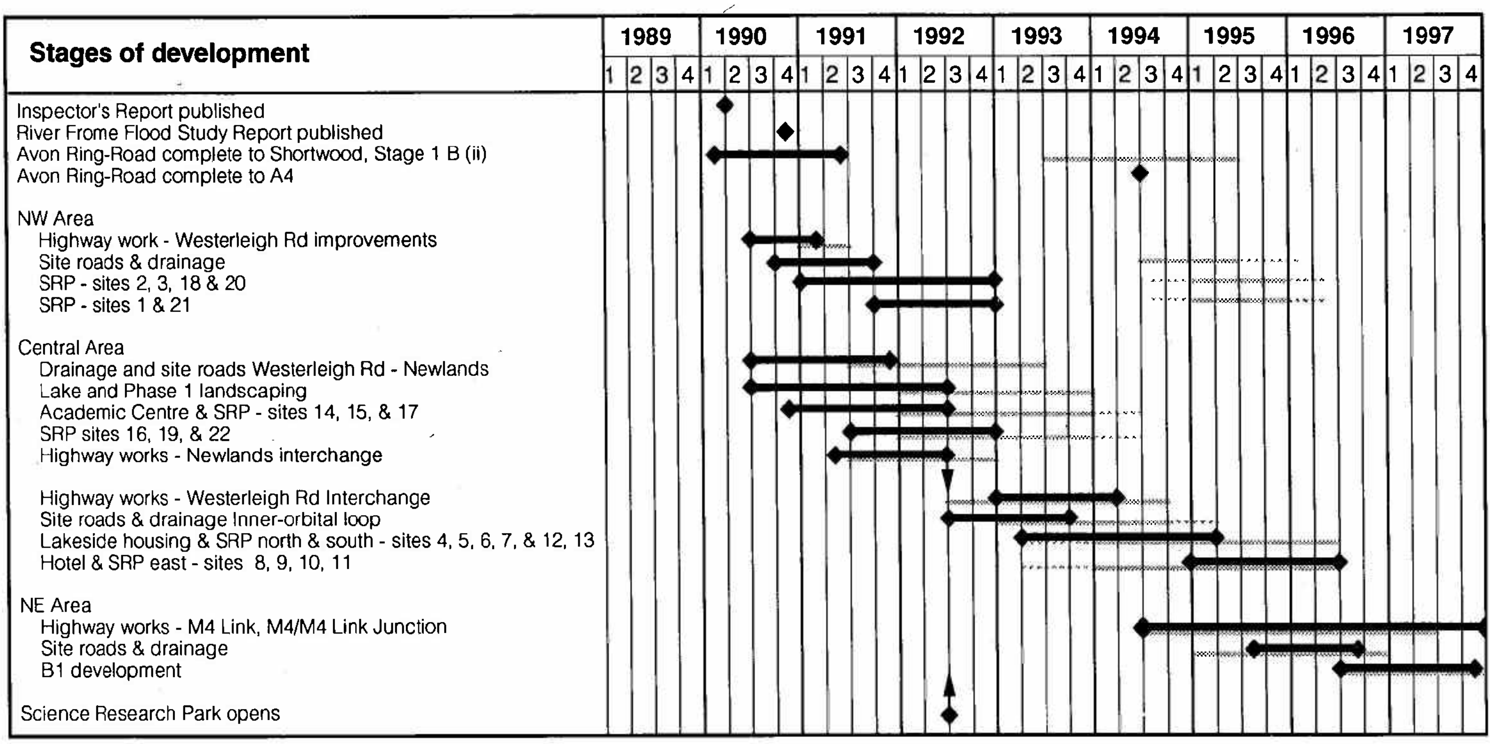
Provision of utilities

The area surrounding the site is well served by all major utilities, and connection and supply to this network will be possible. However, major utility trunk networks cross the site itself. These include an overhead 275 KV electricity line, a 500mm diameter gas main along Lyde Green Lane and a 700mm diameter water main along the northern boundary of the site adjacent to the M4 motorway, and passing beneath it via the existing underbridge. Diversion or relocation works are not anticipated for the overhead electricity line, but locally may be required for the gas and water mains adjacent to the bridge structures.

Construction programme and phasing

The construction programme for the development will follow those of the major highways, with that of the Avon Ring Road being of prime importance. A draft programme developed for the highways construction indicates that the principal highway elements serving the site could be constructed over a seven year period (Figs 4.6, 4.11). The infrastructure of the science park itself will be constructed in

Fig 4.11 Complete EGSRP construction programme proposals



parallel with this, together with the science park academic centre and housing development south of the ring road.

Buro Happold have been involved with the preliminary engineering design and feasibility of the science park since 1987, and more recently have been responsible for preparation of detailed planning application for the major highway network, valued at approximately £24m. In late 1988 an outline planning application was made by the project architects, Renton Howard Wood Levin, for the science park development, Buro Happold providing supporting engineering input to this application. At the public inquiry held during 1989 the Practice also provided engineering evidence in support of the science research park concept envisaged in the local plans.

Present work includes detailed negotiations with the planning and highway authorities together with the Department of Transport, to finalise the highway proposals with particular emphasis on the junction with the M4 motorway, and connections and access to the Avon Ring Road.

It is anticipated that the deliberations of the public inquiry will be made known mid 1990 and, on the basis of a satisfactory outcome, negotiations for land purchase, detailed planning matters, agreement regarding contribution, and other technical matters with public bodies will then be finalised. The objective is to commence site works for infrastructure during 1991 and to construct the north western access roundabout at Westerleigh Road at this time, so permitting work to commence on the science park itself. Construction would proceed in the various phases as indicated in Fig 4.11 with completion of the EGSRP after 1996.

The development of the Emerson's Green Science Research Park offers a bold and exciting challenge in terms of engineering, planning and architecture, to create a completely new environment for science-based campus development. Similarly it provides an ideal opportunity to work in a multi-disciplinary professional environment to attain successful completion of the project. With the support of the local authorities, a high quality development will be achieved bringing recognition of the many professional design skills involved, but more particularly bringing benefits to the academic institutions and to the greater commercial environment of the Bristol area.

Vincent Grant and John Froud

References

4.1 TD22/86 'Layout of Grade Separated Junctions'. Dept of Transport. 1986

4.2 TD 9/81 'Highway Link Design'. Department of Transport. 1981

4.3 NERC Flood Studies Report. 1975

An Atrium at Buckingham Gate, Westminster

Project data

Client	Chesterfield Properties Ltd
Main Contractor	Lovell Construction (London) Ltd
Architects	Rolfe Judd Group practice
Structural Engineers	Beer and Partners
Structural Engineers (Atrium)	Buro Happold
Services Engineers	Tucker Associates
Services Engineers (Atrium)	Buro Happold
Steelwork Subcontractor	Nusteel Structures Ltd
Project Value	£33m
Completion Date	1988, Winner of Westminster Society Award 1990.

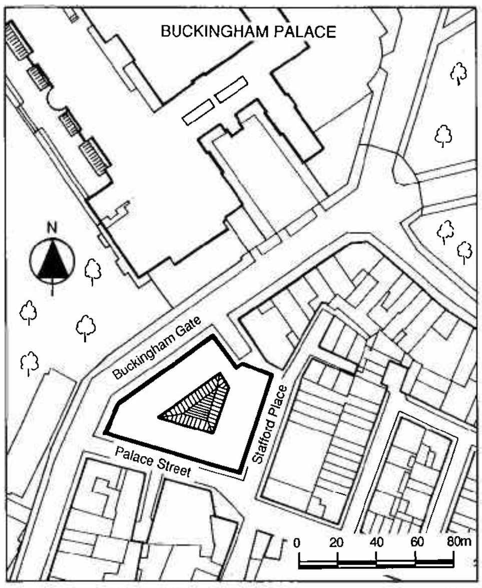


Fig 5.1 Site plan of Buckingham Gate development

Fig 5.2 Inside the completed atrium courtyard

Buckingham Gate is a major £33m redevelopment scheme located in Westminster adjacent to Buckingham Palace, consisting of a triangular covered courtyard surrounded on two sides by important historic buildings (Fig 5.1). Buro Happold were commissioned to design and co-ordinate the fire safety, environmental aspects and structural engineering for the atrium roof construction within the development.

Initially a management contract was adopted, at this time office and hotel options being developed to an advanced stage. However, the client finally made the decision to change to a design build contract for the construction of offices for the Department of Energy. With the varying contractual situation and the relatively large numbers of consultants involved, careful planning and co-ordination were paramount to the successful completion of the project.

Environmental design

Although the brief undertaken by Buro Happold involved the environmental design of the atrium only, such design cannot be considered in isolation from the remainder of the building (Fig 5.2). Thermal, visual and acoustic qualities of the surrounding occupied spaces are affected directly by the form of the atrium. The provision of a roof over a courtyard is no more than an elementary environmental filter. However, the shape of the roof, its orientation, structure and shading capability all determine the degree of filtration which occurs.

The brief for an atrium such as this is as important as that of any part of the building. The client must be aware that decisions made early in the sketch design on its intended immediate and future usage have a profound effect on the design development of both atrium and surrounding buildings. The implications of such change of usage in terms of environment and fire engineering need careful exploration.

The brief required the atrium to be a transient space and one which responded to hourly, daily and seasonal changes in the external climate. Quite wide fluctuations in temperature can be tolerated in such spaces; indeed their success is in providing a refreshing alternative to the closely controlled air conditioned environment of the surrounding offices (Fig 5.3a, b).

Roof form

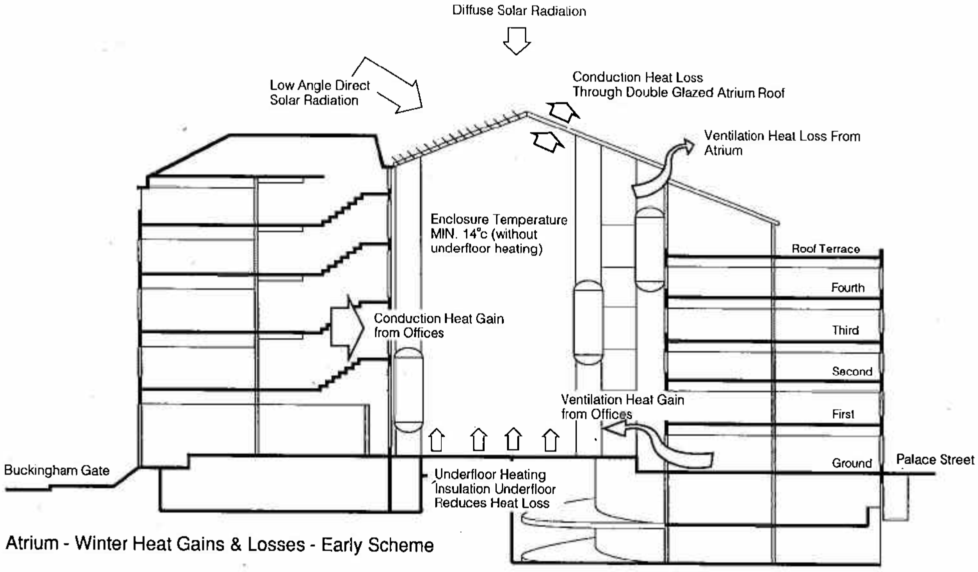
The form of the roof was influenced by the relationship of the surrounding building facades, the heat gain both directly to the atrium and indirectly to the occupied buildings, the quality of natural lighting and the need for maintenance access to the roof.

Several alternative forms were considered before the final design emerged. Structurally, this chosen form with its dominant inner ring beam, addressed the elevations well whilst the orientation of the inner pitched sections of the roof was a result of the need to keep solar gain within agreed limits (Fig 5.4a, b).

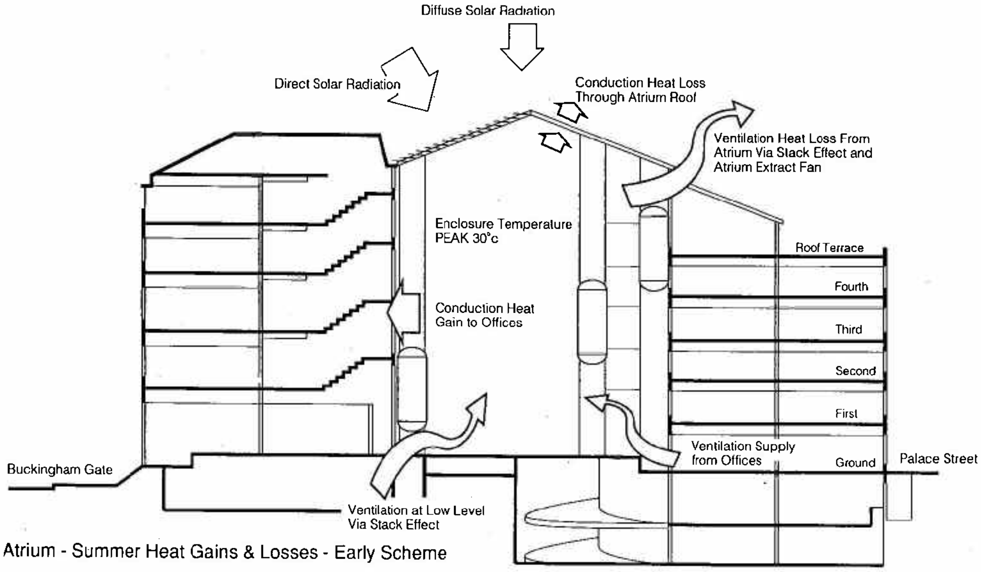
Shading requirements and solutions

Due to limitations on maximum cooling capacity of the air conditioning systems in the office accommodation, it was essential that the whole roof design worked to a limited solar gain factor of 0.3. A blanket coverage of shading was one possible solution, solar reflective glass another. However, both of these would have been detrimental to the quality of the atrium interior. The colour of natural light is a quality which is desirable to maintain, both in working environments and more importantly in such transient spaces. Clear glass was therefore a principal requirement, whilst double glazing ensured reduced heat loss and minimal condensation problems. Equally, any shading used must have variety. A blanket coverage of shading, whilst being useful for minimising night-time radiation losses, would allow only diffuse light to penetrate the space and would be monotonous – a variety of lighting is desirable. By increasing the extent of shading to the central roof it was possible to omit any shading to the perimeter zone around the ring beam and still meet the target solar gain factor. Shading to the central roof consisted of externally-mounted, remotely-controlled, motorised blinds on the southern aspect of the pitched roof, with further significant contribution from the roof structure and the access walkways below the pitched sections.

In this manner solar gain was reduced, yet direct sunlight could penetrate the atrium at all times of the



Atrium - Winter Heat Gains & Losses - Early Scheme



Atrium - Summer Heat Gains & Losses - Early Scheme

Fig 5.3a,b Winter and summer heat gains and losses in atrium – early scheme

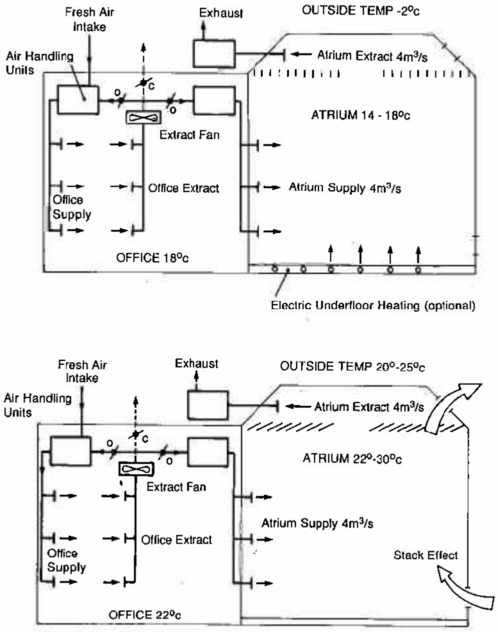


Fig 5.4a,b Temperature control in winter and summer – early scheme

year, to the benefit of occupants and to emphasise the quality of the building elevations (Fig 5.5a, b).

Temperature control

Upper and lower temperature limits within the atrium were determined by maximum heat gains and losses to the office accommodation. To maintain this level, a mechanical ventilation system was introduced at high level in the atrium, served from a central boiler and chiller plant. Temperature limits within the lower atrium were maintained by projecting a limited proportion of the supply volume from jet flow diffusers from high level. As a further measure to limit upper temperatures, opening roof lights were provided in the central roof. These have a second function of smoke extract ventilation.

Fire engineering

A variety of solutions for the atrium fire safety were discussed when considering the various office and hotel options. The use of drenchers, toughened glass and fire resistant glazing were all considered for use in the atrium elevations, each with a suitable smoke control scheme (Fig 5.6). Finally however, a solution which allowed the atrium base to be an office area was adopted, using half hour non-insulating fire resistant glazing. The exception was the existing listed stairway which was isolated using one-hour insulated glass to ensure safe means of escape. The resultant smoke control scheme was nominal and was essentially for secondary smoke clearance purposes (Fig 5.7).

Structural engineering

The design was developed to ensure a balance consistent with all of the technical criteria without compromising the fundamental requirements for stability, and to provide an agreeable, comfortable and safe working environment. Being five storeys high and with a maximum span of some 25m, the atrium required a roof structure which would be both bold in scale and consistent with surrounding buildings.

Early discussions were concentrated on the level of the atrium roof, which was strongly influenced by architectural spatial requirements, the need to retain a fully visible elevation to the existing buildings, and fire and environmental engineering considerations. A number of criteria influenced the design.

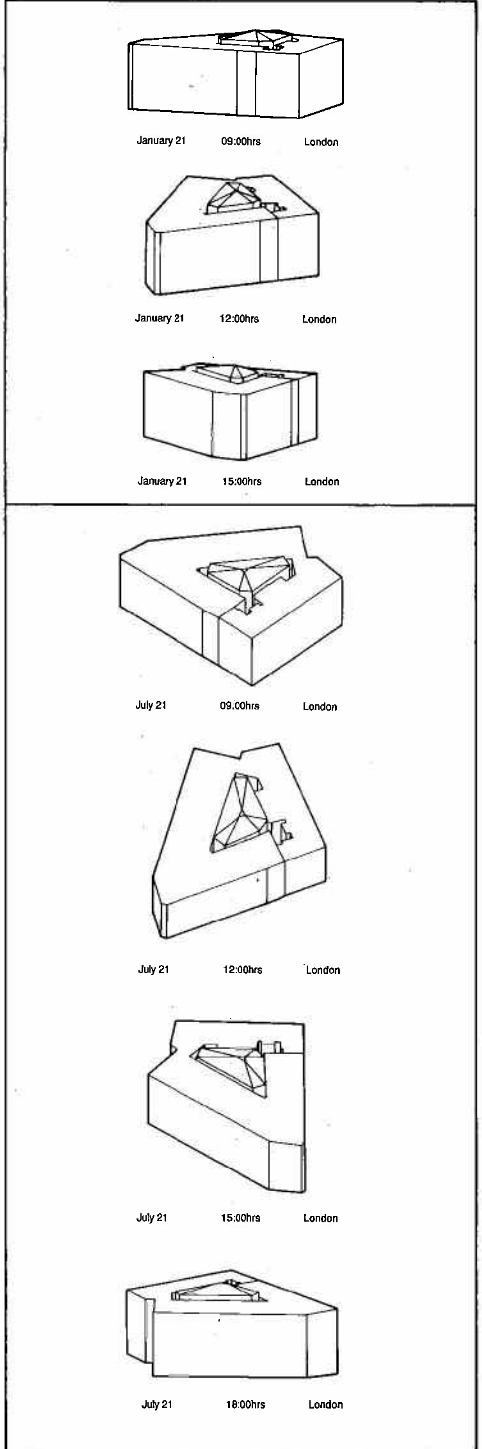
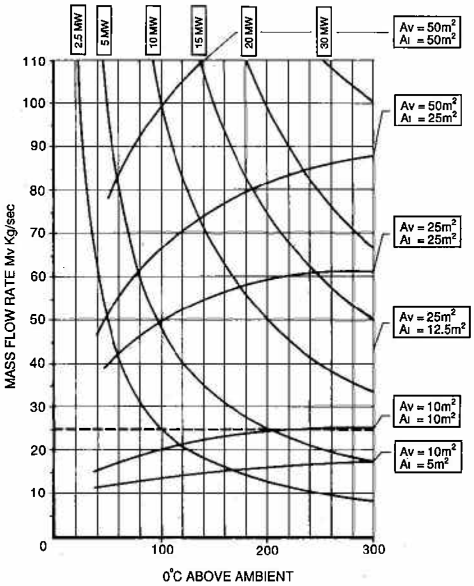


Fig 5.5a,b Sun's eye view of atrium – January and July



Av = Area of vent in atrium roof
Ai = Areas of vent through fire compartment
—— Mechanical system alone

Fire size varies from 2.5 to 30 MW showing that large fires do not cause a significant build up of smoke layer

Fig 5.6 Smoke control analysis graph for atrium

(a) Transfer of vertical load

The relatively high level atrium roof with fairly small loading compared with that in the surrounding accommodation was logically supported on the perimeter buildings. Clearly with new supporting structures, Buildings 3 and 4 could readily be adapted to take additional load. However, existing Building 2, which was to be partially restructured, was arranged to receive the new roof, although it was necessary to oversail the existing roof line for limited areas (Fig 5.8).

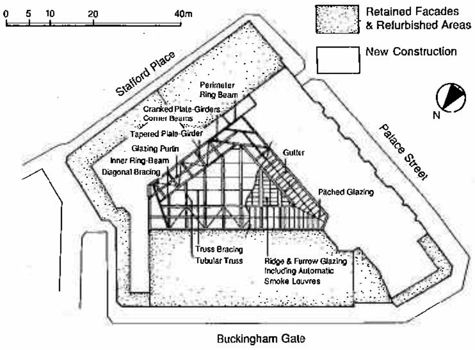


Fig 5.8 Roof plan showing steel work layout and profile o buildings belo

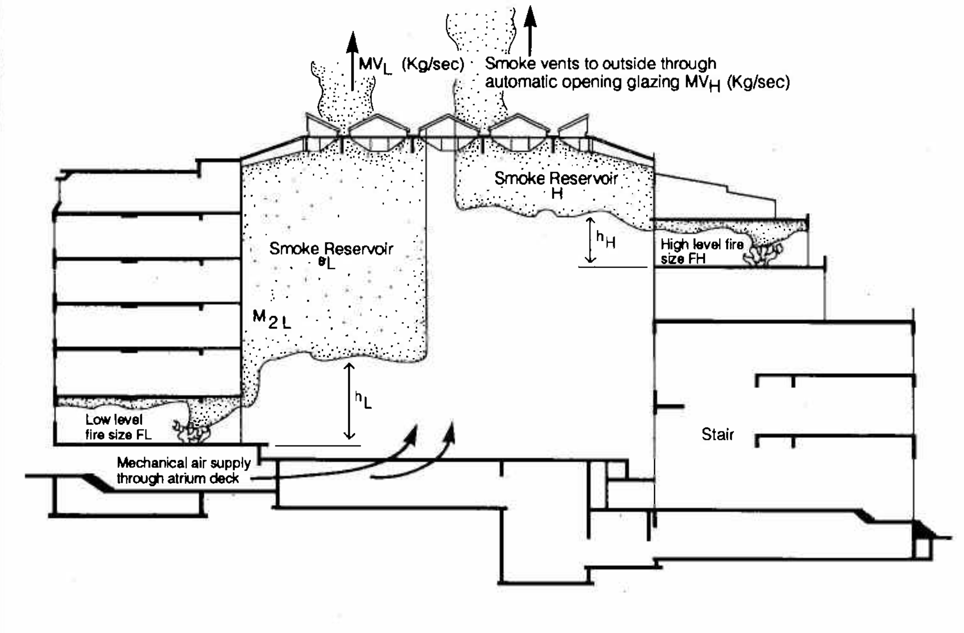


Fig 5.7 Section through atrium – fire engineering design

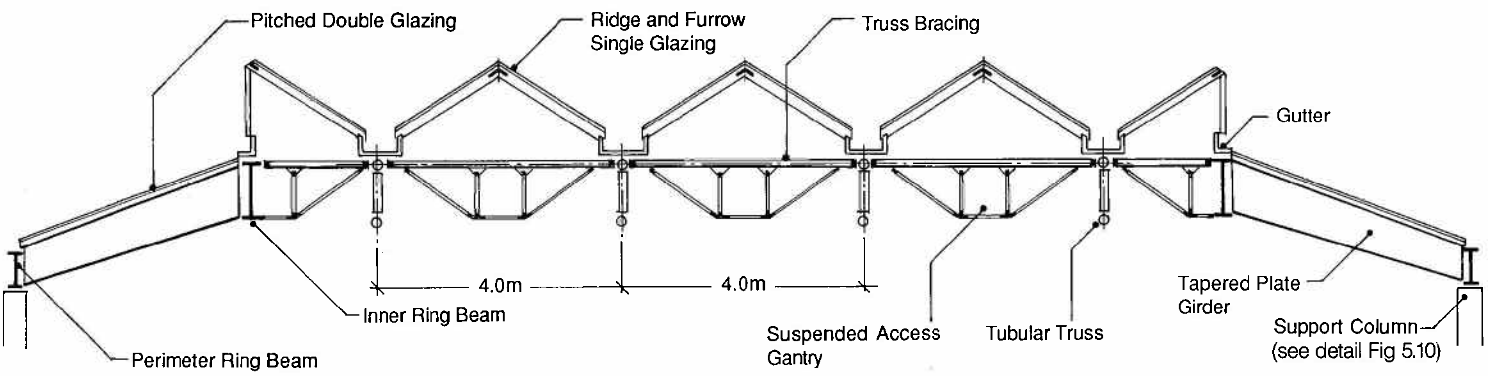


Fig 5.9 Section through atrium roof

(b) Differential movement of supporting buildings and thermal movement

During the construction of the major foundation works, some differential movement of Buildings 2, 3 and 4 was experienced, including significant horizontal components. Although the movement slowed down as works were completed, it was felt advisable to allow for this movement in the design of the atrium roof. The joints and restraints to wind forces were organised in such a way as to allow the atrium roof to breathe thermally and to allow differential horizontal movement of the three buildings (Figs 5.9, 5.10).

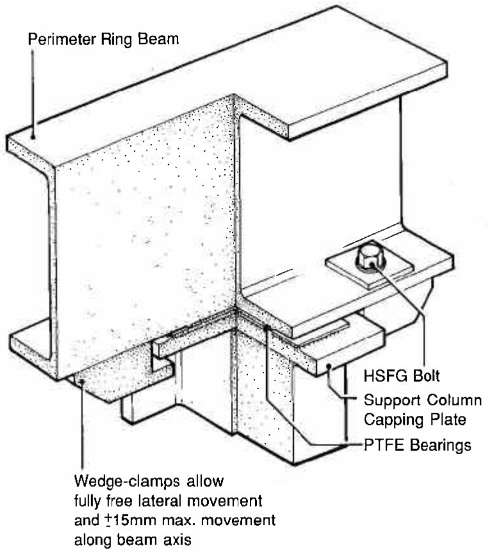


Fig 5.10 Movement bearings carrying perimeter ring beam

(c) Erection of structure

The site is bounded by a major road and two fairly narrow streets in the centre of London. The constraints were such that the potential delivery and erection problems had a significant effect on the design and layout of the atrium steelwork.

The structural solution chosen was to form the roof in four notional plates, three trapezoidal plates inclined upwards at 20° from the perimeter of each building and a fourth triangular flat plate supported on the top edge of the others in the centre. The plate edges were defined by a perimeter ring beam and an inner ring beam, both formed from standard UB sections, the inner ring being supported at each corner by tapered plate girders cranked in elevation. The trapezoidal plates were then formed by tapered plate girders spanning between inner and outer ring beams, which in turn support purlins and the inclined glazing. Each plate is braced with a zig-zag of diagonal tubes. The central triangular plate is formed by a set of seven light, circular tube trusses spanning within the inner ring and aligned perpendicularly to the principal historic Building 2. Hanging between the trusses is a light walkway for maintenance access, the top tube of which provides intermediate lateral bracing to the trusses. The pitched glazing spanning between the trusses rises to a ridge directly above each walkway.

Clearly, such a design had to consider erection sequence most carefully, not just to limit the weight and length of elements by use of splice joints, but also so that the erection process itself did not introduce deflections or displacements which could cause lack of fit and high secondary stresses (Fig 5.11a, b, c, d). This was achieved by stringent geometrical checks as each stage of the erection proceeded. The outer ring beam was first accurately located on its 18 bearing points before the three cranked corner beams were fixed in place. The two shorter lengths of inner ring beam were then inserted between the corner beams and the tapered plate girders placed in sequence from the centre outwards, with additional restraint being provided by tirfors and a central racking strut back to the building below. A single tapered plate girder was then cantilevered out from the outer ring beam in the centre of Building 2, and its free end propped back to the building beneath. This enabled one of the long trusses and a short section of inner ring beam to be slotted in place, spanning the atrium completely. A central point thus formed to which the third and longest length of inner ring beam could be completed, and the remaining tapered plate girders erected. At this stage, the restraining tirfors were kept intentionally short so that the inner ring beam was held just higher and closer to the adjacent buildings than required. This ensured that the remaining trusses could be lowered into place in an oversize gap and then when all were secure, the tirfors released and self-weight would lower and close the last few millimetres.

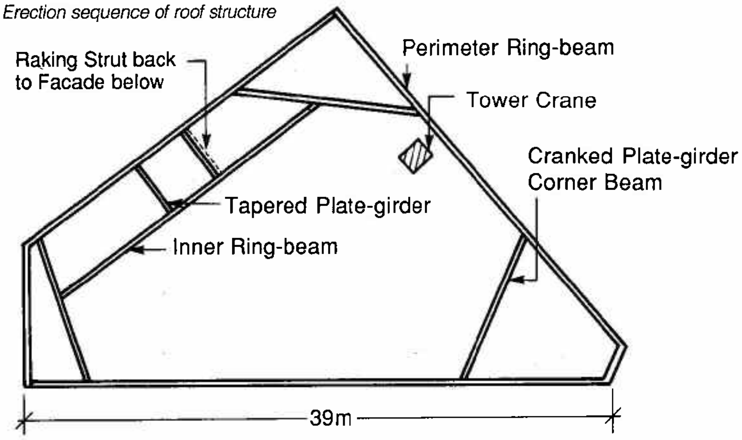
Although the remainder of the steelwork was almost all then erected, a final loosening and locating of some key diagonal braces was made after the placing of all glazing and maintenance trolleys was completed. This ensured that all stresses and deflections associated with the build-up of full dead load could be dissipated and the position of the roof on its bearings given adequate allowance for future thermal and snow load movement.

(d) Internal and external cleaning

In atria and other glazed enclosures there is a conflict between measures required for convenient cleaning and the need to maintain the clarity of the original design concept. If at all possible, cleaning using a vehicle from the atrium deck is a useful compromise. However, in this case the roof was too high and a cleaning gantry was provided (Fig 5.12).

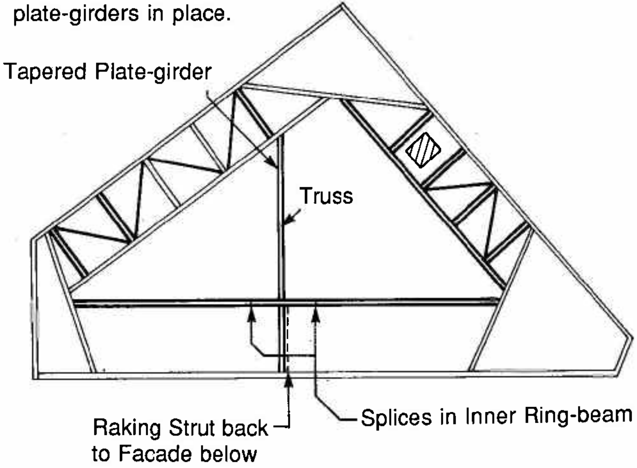
Mick Green, Peter Moseley and Ben Kaser

Fig 5.11a,b,c,d   Erection sequence of roof structure



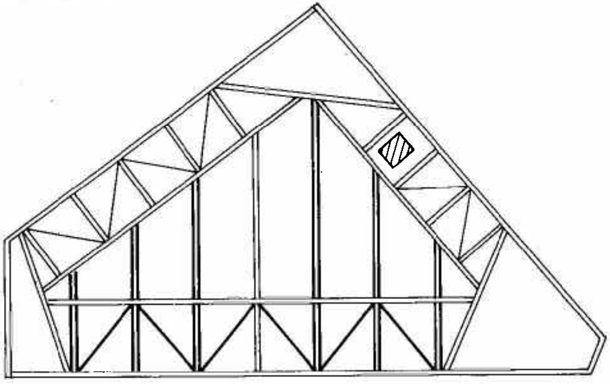
a

Perimeter ring-beam and corner beams allow lengths of inner ring-beam to be supported with single raking strut before all tapered plate-girders in place.



b

Plate-girder with raking strut supports cruciform of truss and short length of inner-ringbeam before longer length inserted



c

Remaining trusses and plate-girders erected in pairs before bracing completed

d

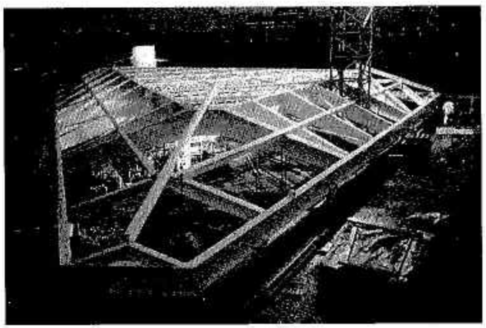


Fig 5.12   Cleaning gantry high in atrium enclosure.

Lighting the High-Tech Office

Fig 6.1 Uplighting provides even wash of light over surfaces while neutral tone translucent blinds help control day light

Buro Happold has always supported the work of the engineering institutions. We feel that as we gain from the knowledge contained in their publications, it is only right that we contribute to the production of such documents. By releasing staff who wish to become involved in Institution activities, we hope that others may also gain from our knowledge. One recent example of such involvement is the new lighting guide LG3 'Areas for Visual Display Terminals', from the Chartered Institution of Building Services Engineers. This was produced by a CIBSE task group chaired by one of our staff. Below he outlines the main points of the guide and gives some insight into the thinking behind its production.

Visual display terminals (VDTs) are increasingly to be found in our office spaces. More people now use them for longer periods and for increasingly important tasks, demanding a screen image of the highest possible quality. The best way of achieving this is to select a good quality screen – one with a stable display of well-formed characters, a high refresh rate and a good range of tilt and swivel adjustment. Once delivery has been taken of these new screens, be they standard PCs or of the newer high-tech type, design staff must ensure that environmental factors do not degrade the quality of the images produced. The most important of these factors is the lighting of the office space (Fig 6.1).

Lighting plays many parts in a well-lit interior, not only providing sufficient working light and a pleasant lit space in which staff can work, but also enhancing the architectural quality of the space itself. If the lighting is inadequate it can distract those at work, present a poor image to outsiders, may produce certain ill effects in the staff, and it may well degrade the quality of the screen image on the VDTs. To ensure that the positive aspects predominate it is vital that the lighting is considered at the same time as any move from desk-based to terminal-based work. To venture into new technology without considering the lit environment may well lead to a poor return in investment and much staff discontent.

However, many other factors both directly and indirectly affect the use of VDTs. A poor choice of chairs and desks may lead to postural problems. Inadequately adjusted ventilation may cause draughts or drying of eyes. Furthermore, poor staff liaison may even lead to staff resistance and a search for 'something to complain about'. Although the new guide is mainly concerned with the lighting of the space, it has described these problem areas so enabling them to be identified and separated from any technical lighting problems that may occur.

The main aim of the guide is to describe how complaints may arise on the introduction of VDTs, methods of identifying sources of these complaints and the means by which good lighting design can avoid them. The design section considers ceiling mounted light fittings, uplights, combined up/downlights, with desk lights and with less usual forms such as cornices or luminous ceilings. It is suggested that all these techniques can be used successfully in VDT areas providing criteria in the guide are adhered to. Designers who may state sweepingly that 'uplighting is the only thing that really lights VDT areas properly' or 'downlights are a must in CAD areas' are showing a limited grasp of the problems and are a menace to the client, a bane to the architect and a millstone around the neck of those who have to work in the space.

Principle points of concern when considering any lighting system include the possibility of reflections in the screen, the existence of areas of high luminance in and around the VDT, which may cause difficulties in adaptation to the generally low screen luminance, and the location of areas of high luminances away from the VDT itself, which may be a source of distraction. In order to avoid such problems the designer must limit the luminance of screen reflections, limit the range of luminances of parts of the work station viewed in quick succession by the user, and limit the brightness of objects and surfaces beyond the screen.

The first problem, that of screen reflections, is the one most often cited as a source of complaint. The solution is, however, simply stated in principle. If a VDT is assumed to be standing on a desk and viewed by someone sitting in front of it, then by limiting the luminance of the luminaires and room surface that can be seen from the screen (behind the user), one will also limit the luminance of reflections on the screen (Fig 6.2). The lower the luminance of these luminaires and surfaces, the lower the luminance of the screen reflections. Putting that simple statement into practice can be difficult. The room surface luminance depends both on the surface reflection and the illumination of that surface. To keep the room surface luminances fairly constant, the room surface reflections and the illuminance of those surfaces should be kept as even as possible. A sudden white painted column on a brown wall or a bright splash of light on the wall, could show on a screen as a distinct and distracting object.

The downlighter today remains the predominant style of lighting in offices, principally because of the effective control it offers in the luminance of the luminaire as seen reflected in the screen. Luminance must be limited above the angle that the luminaire is seen from the screen in order to achieve such control. If all the ergonomic criteria of the terminal and operator are known, then this luminance limiting angle can be derived by simple geometry (Ref 6.1) (Fig 6.3).

Because such information is not usually available to the lighting designer, and because of the multiplicity of tasks and screen types used in most interiors, three standard categories of luminaire have been defined in the guide. These categories can be described broadly as Category 1, for areas where screens are constantly referred to or where errors in reading screen information have severe consequences; Category 2, for areas where screens are used intermittently or where accuracy is important; and Category 3, for areas where VDTs may be used only occasionally or where the screen content is of minor importance.

Manufacturers have now started to publish the categories achieved by each of their luminaires, so permitting the simple selection from their ranges of the correct type of luminaire for any particular application. Determination of the correct category takes some careful thought. If the category selected is too low for the space then problems may occur with screen reflections affecting performance. Conversely, if too high a category is selected, then not only are the higher quality luminaires themselves more expensive, but also their tighter optical control means that they are generally less efficient and have a lower spacing requirement, necessitating the installation of a greater number of light fittings.

Of course even when the right lighting solution has eventually been determined the lighting designer still has the problem of persuading the interior designer not to use those fashionable black desks, the architect not to specify a glossy ceiling, the quantity surveyor not to strike out the sum against those essential blinds for the windows and the client to pick up the cheque book. Perhaps with a copy of the lighting guide and a bit of luck we might succeed.

Paul Ruffles

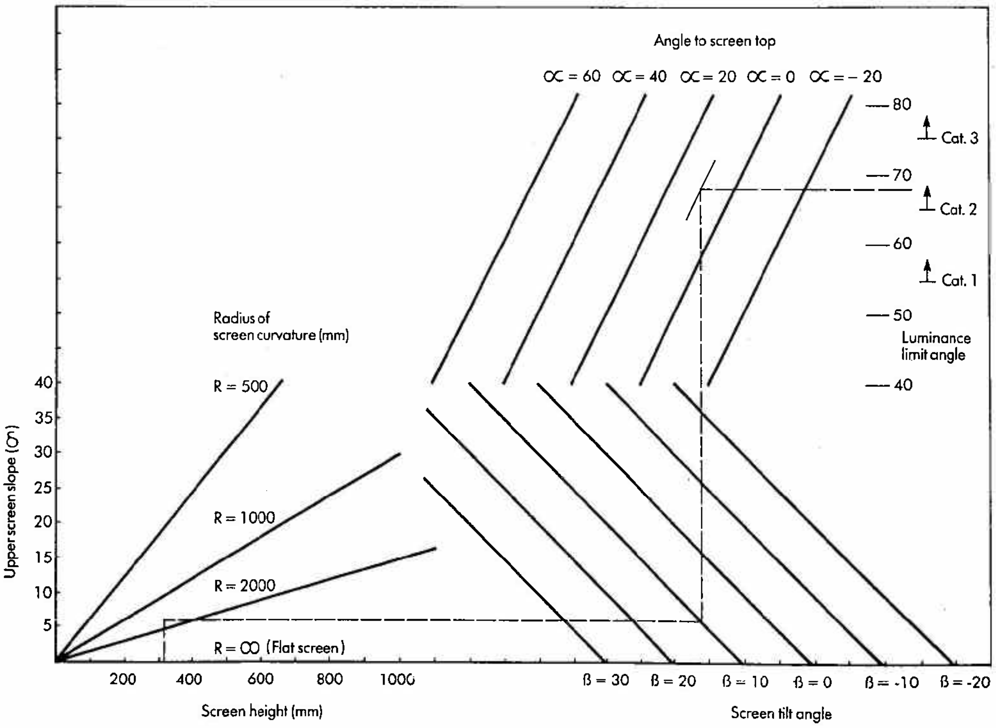


Fig 6.2 Nomogram of factors that determine luminance limit necessary for any given installation

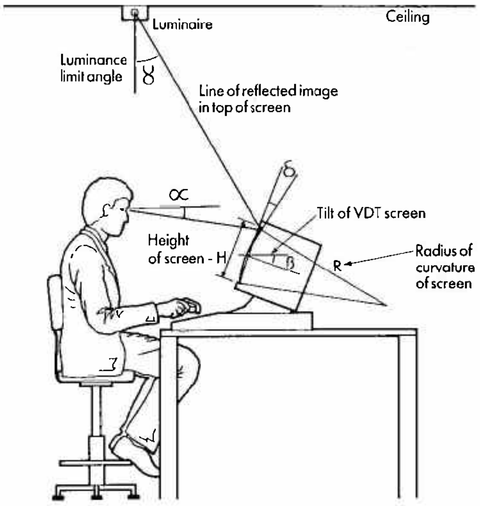


Fig 6.3 Typical geometry for eye, screen and luminaire

References

6.1 LG3 'Areas for Visual Display Terminals' Appendix 2 Downlight luminaire design. A2.1.1 Luminance limit p23. CIBSE 1989

Restoration Behind the Listed Facade – Colonnades, Bath

Project data

Client	Grosvenor Square Properties
Architects	Rolfe Judd Group (Partner in Charge: Tony Judd)
Interior Design	Crightons Ltd
Consulting Civil, Structural & Services Engineers	Buro Happold
Qualtity Surveyors	V J Mendoza
Main Contractor	Kier Western
Subcontractors	
Structural Steel	Tetbury Steel Ltd
Demolition	Longs of Bath
Electrical	Longs of Bath
Mechanical	Multiheat Ltd with Nuaire
Cost	£3.5m
Completion Date	October 1988

In 1985 Bath City Council accepted a tender from developers Grosvenor Square Properties for the development of the site of the disused Spa Treatment Centre and adjoining Royal Baths swimming bath located in the centre of Bath. The facade looking onto Bath Street is Grade I listed and forms part of one of the finest pieces of townscape in Britain, linking the Georgian bath buildings with the Pump Room and Abbey Churchyard complex (Fig 7.1a,b). The scheme, prepared by architects Rolfe Judd Group Practice, needed to be an attraction in its own right if it was to draw customers from the nearby main shopping street.

The central concept of the development was for a naturally lit and ventilated, but covered shopping mall overlooked by the individually serviced shop units, all located behind the famous listed facade. Finishes were to be of the highest standard and the interior design was an important element of the scheme from the earliest stages.

The original plan was to demolish the Victorian Royal Baths and to build new shops and a mall on three levels on this site, with the lower three floors of the Georgian Spa Treatment Centre being converted to shops opening onto the mall. The top level floors were to be left as offices and were not part of the original 'pre-fire' scheme. (Fig 7.2a,b,c)

No individual feature of the Colonnades project is of great complexity but as a whole the project required the solution of a range of engineering problems not normally encountered on one relatively small job.

Archaeology of site

Bath was an important Roman town and extensive excavations carried out on adjacent sites over the past 100 years had indicated that much interesting archaeology lay under the proposed development. There were likely to be Roman archaeological remains beneath the site and accordingly, the developers agreed to fund the Bath Archaeological Trust to carry out detailed investigations during the early demolition stages.

As the new works required demolition to below existing basement level, there was a need for extensive temporary shoring. The excavation and shoring bases would destroy any archaeology and so a scheme for the demolition and shoring was prepared, and a programme of works agreed, with the archaeologists to minimise delays to the project and to allow the archaeologists access to all parts of the site of interest to them before they were damaged by new construction. Archaeological excavation was thus phased into the demolition of the Victorian buildings. Successive layers of medieval Saxon and Roman remains were uncovered, thereby helping to clarify the history of this important site and extending knowledge of Roman Bath.

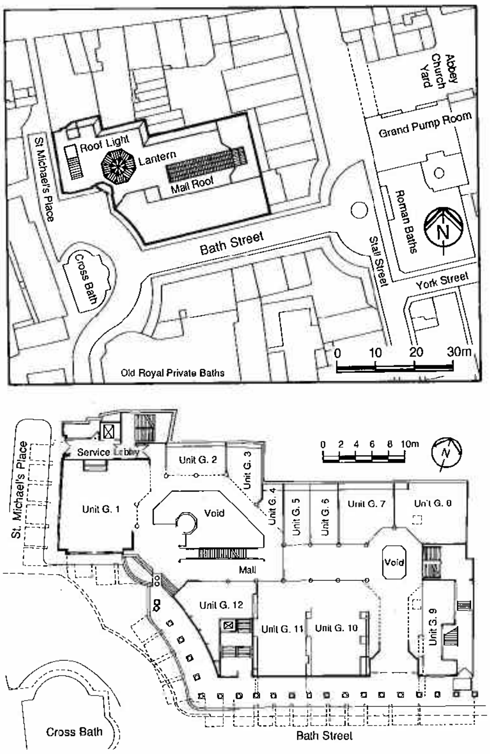
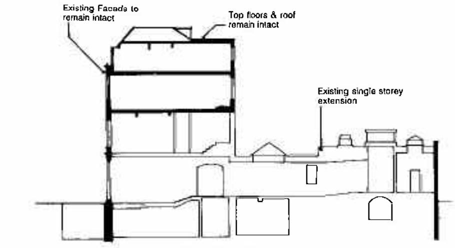


Fig 7.1a Site plan of Colonnades development
b Ground floor plan of mall and shop units

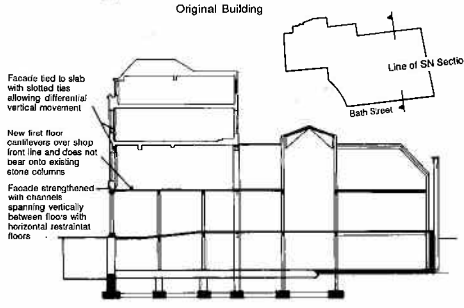
The Romans had built their town on the terrace deposits overlying the lias clay. Saxon and medieval buildings were later constructed over the ruins of the Roman town, followed by a further raising of the general level of the centre of Bath during the eighteenth century by Georgian developers. The Georgian buildings were built on top of Saxon and medieval deposits with a minimal amount of disturbance to the Roman remains, which now lie not far below the floors of Georgian cellars. Interestingly, the strip of land between the Georgian buildings on Bath Street and Victorian buildings behind was found to predate both buildings and contained extensive Saxon remains in the form of wells, dung and rubbish heaps.

Site investigation of contaminated ground

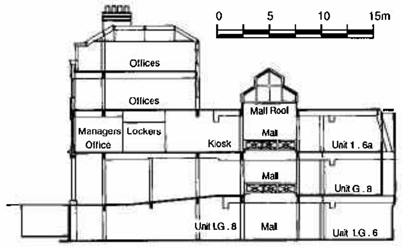
The Spa Treatment Centre had been closed in the mid 1970s when the hot water supplying it from shallow wells put bathers at risk, having been contaminated with pathogenic amoebae. Deep boreholes were drilled in the early '80s to provide uncontaminated hot spa water from permeable limestone layers in the lias. However, the ground on the site was still potentially contaminated, and trial pits to establish both site soil conditions and levels of existing foundations had to be carried out under the strict conditions required of a contaminated site. This involved the use of masks and goggles, clothing laundered at the end of each day and site showers for the work force. However, samples taken during the investigation were tested and found not to be contaminated so allowing conditions to be relaxed for the following works.



Original Building



Scheme 1 - Before Fire Damage



Final Scheme - General Arrangement

Fig 7.2a Original section through site
b Section through "pre-fire" development proposals
c Section through final development

Demolition and shoring

The demolition contractor chose to work to the methods and sequences devised by Buro Happold for the agreement with the archaeologists. However, with remains of buildings of different ages in the site it was difficult to clearly understand which pieces of walls and vaulting were structural and which were redundant remnants. From their extensive research in the archives of Bath Reference Library the archaeologists were able to advise on the buildings on the site over the past 300 years and this helped to unravel some of the structural mysteries.

The building, although listed because of its facade, had been much altered since it was built by Thomas Baldwin in the late 18th century. The facade is constructed of Bath stone only 150mm thick and had originally been stiffened by timber battens, later replaced in areas by blockwork and steel angles but in all cases notched back to the timber floor. There were Georgian vaults which had been backfilled in Victorian times to provide a stable yard for an adjoining inn, which was itself demolished over 100 years ago. These vaults were cut through by Victorian walls which although only one storey high were the remnants of a four storey extension to a 100 year old hotel demolished 20 years ago. Details of the foundations of these walls, which lie on the site boundary, had been recorded by a Victorian archaeologist.

Demolition works were closely controlled to ensure that the adjoining properties, some of which were infill buildings, were adequately shored and that foundations were not undermined. By agreement, the archaeologists were also required to work under the supervision of the structural engineer when working near foundations.

Damaged by fire

Full tender documents and detailed design for the original concept of refurbishment had been completed when on Saturday 26 July 1986 a fire gutted most of the retained building on Bath Street. The existing timber floors were extensively damaged, leaving the four-storey facade in a very precarious stage as it was no longer tied back to the buttresses of the chimney stacks behind. It was too dangerous to enter the building and shoring was necessary as a matter of the greatest urgency. A raking scaffold shoring system was erected within days using ladder beams and screw jacks to fix the facade and puncheons off the facade, and mass concrete kentledge to provide the weight needed for stability against the westerly winds (Fig 7.3).

Assessment after fire

Once the fire brigade and police had completed their investigations, the engineers were able to enter the remains to assess the extent of fire damage. Insurance assessors, conservation groups and the Bath City Council authorities all had to make their own assessments. The structural engineers reported that substantial parts of the building were damaged beyond repair and were unsafe. Large parts of the building had to be demolished to make it safe before any work at all could continue. Once these areas were removed, there was so little left that the conservation groups and the city authorities did not object to total demolition of all except the facade.

The original building had been extensively altered over the years, most recently in the 1970s, leaving in reality the facade as the only valuable part. All efforts were therefore directed towards saving it. The whole of the site was cleared by Longs, leaving the spectacular sight of the facade standing alone some 20m above the excavated basement level (Fig 7.4). From the access provided by scaffold shoring, an assessment was made of the extent of damage to the stone. It was found that a substantial length of parapet in the area where the fire had been most fierce was badly cracked and would need to be replaced. Complete removal and re-erection of the facade was considered but rejected by conservation groups during preliminary discussions. However, the parapet was taken down and rebuilt using a mixture of new stone and whatever original stone could be salvaged. Some existing vertical cracks in the facade had also widened due to thermal expansion and blocks here were removed and replaced (Fig 7.5).

In the 1970s' refurbishment, the original timber lintels over the colonnade columns had been replaced by steel I-beams, continuous over pairs of columns. During the fire, new cracks in the column heads had appeared at the ends of these I-beams caused by expansion and subsequent contraction of the beams. It was decided to use epoxy grout in the cracks to prevent the ingress of water and progressive frost damage.

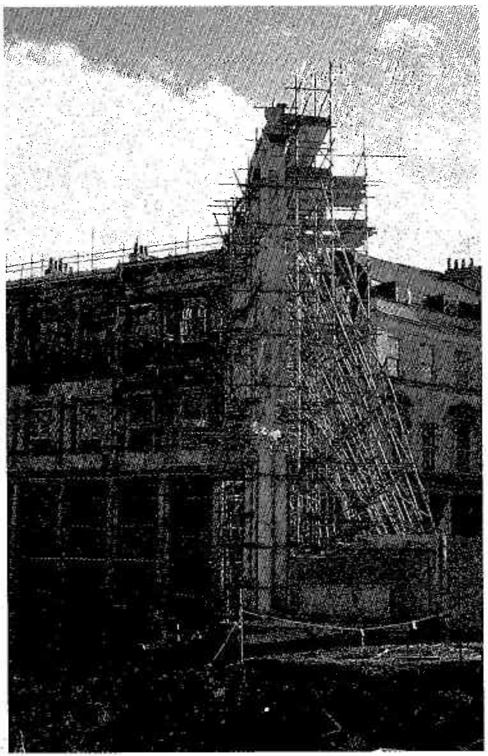


Fig 7.3 Facade with temporary shoring

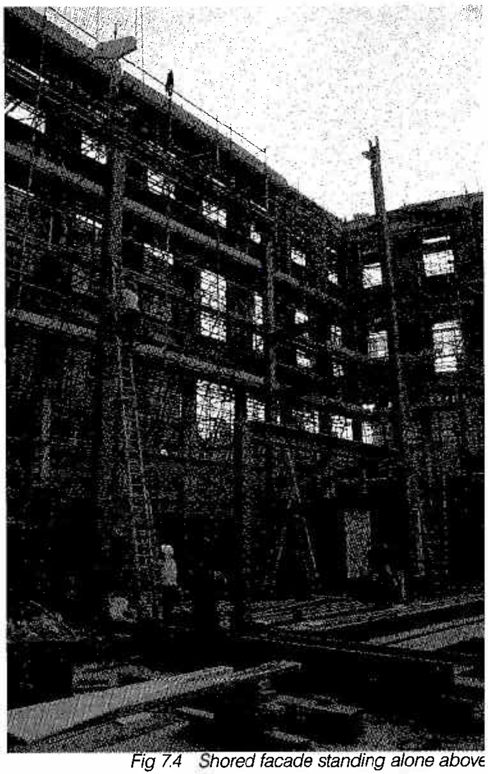


Fig 7.4 Shored facade standing alone above excavated basemen

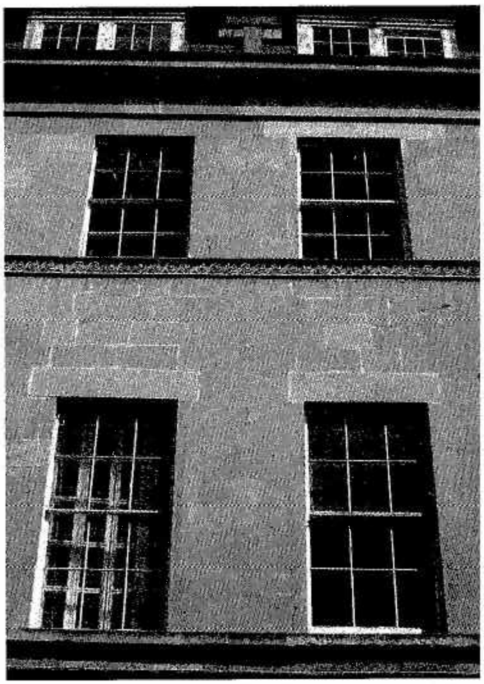
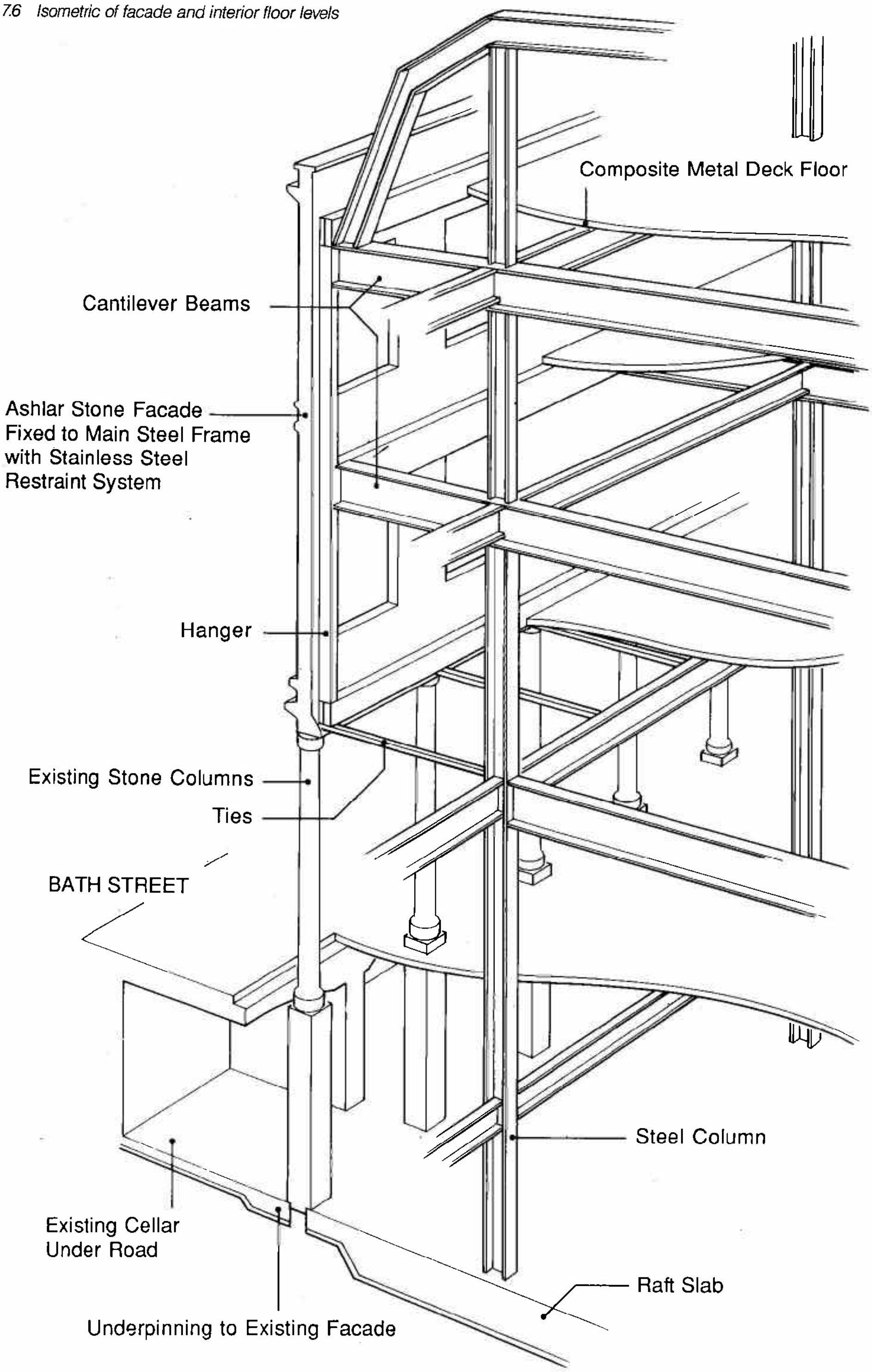


Fig 7.5 Repairs to stonework of the facade

Fig 7.6 Isometric of facade and interior floor levels



On completion of all assessments, the Building Control Officer ruled that apart from the facade, repairs would involve such a substantial amount of work that it would be considered a new building and so would have to comply with foundation and disproportionate damage requirements of the Building Regulations. This meant that the building could not be reinstated as previously built and the insurance assessors agreed to its demolition and reconstruction as a modern structure. Engineers and architects hastily returned to the drawing board. The same essential concept was retained but to be built as a modern structure on new foundations with new services behind the restored facade.

Foundation and retaining walls

The new structure is founded at the lower ground floor on the terrace deposits on a reinforced concrete raft slab, 300mm thick under the three storey section and 800mm thick under the five storey section. The existing facade foundations were built into the new raft and ground slabs so preventing further differential movement at basement and ground levels, and enabling the pavement to be effectively tanked to waterproof the basement.

Baldwin undoubtedly was a great architect but his foundations for the original building were meagre and had settled substantially over the years, resulting in much cracking to the original buildings. The colonnade foundations were easily strengthened by casting them into the raft slab. Where the original Georgian vaults extend under the surrounding roads, they are retained. On the other side of the site the ground is retained by reinforced concrete retaining walls cantilevered off the raft slab and supporting structural columns.

Whereas the new building is supported on the same ground used by Romans and Victorians for their foundations, the Georgian structures had been founded on the Saxon and medieval fill materials!!

Facade restraint and repairs

The floor joists of the original building had spanned on to notches in the stone facade, thus providing lateral restraint. The new concrete and steel building with modern shop and office loads could not be supported by the thin ashlar stonework, and new supports could not be provided on the facade line through the colonnade (Fig 7.6). The new structure was therefore designed to cantilever at second and third floors from the shop front line. Horizontal restraint to the facade, allowing for differential vertical movement, was provided at each floor level (Fig 7.7). The thickness of floor at first floor provided inadequate depth for a cantilever and so this level was hung from the upper floors.

The facade stonework was strengthened using

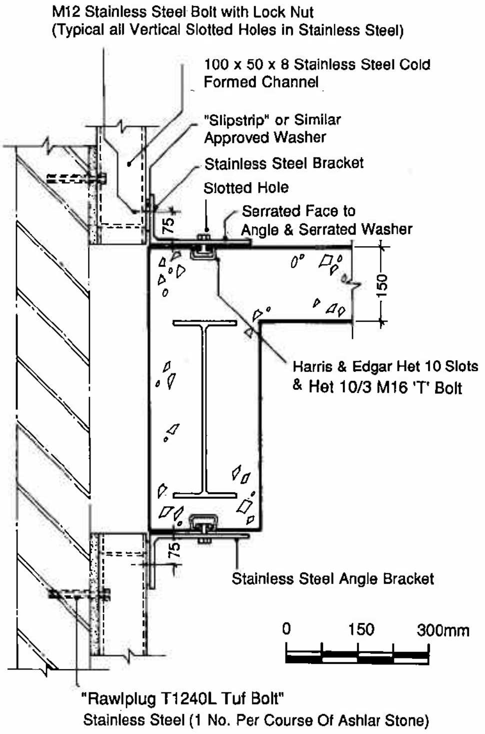


Fig 7.7 Facade restraint details shown on section through facade

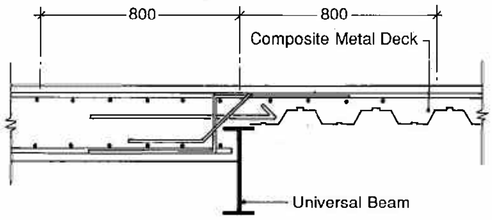


Fig 7.8 Typical edge detail of concrete slab

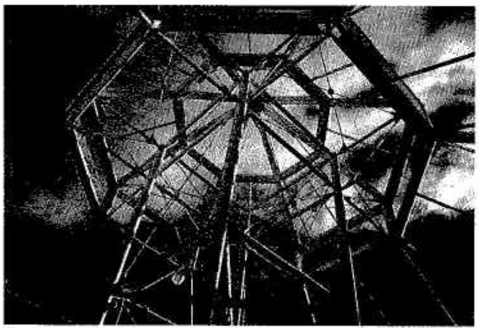


Fig 7.9 Feature steelwork and glazing of atrium

horizontal and vertical stainless steel angles around the windows. These angles were bolted through vertically slotted holes to angles fixed to the new structure, by angle brackets bolted into channels. In this way construction tolerance was provided in all three directions to allow for the variations in alignment of the facade.

The original facade piers, founded on soft ground, had clearly settled over the years so that various ad hoc repairs of brick infill between the colonnade columns and piers had been made. Steel beams had been inserted to support the road and pavement and as these were very badly corroded they were removed and replaced with new beams encased in concrete. Column bases were grouted to fill all voids, and piers which had deteriorated badly were encased in reinforced concrete jackets. During these repairs one of the stone columns developed cracks. It was removed, the cracked section replaced and the column then rebuilt.

Vaults – Refurbishment and waterproofing

The Georgian arched vaults extend under the surrounding roads and had caused some concern in the past with the collapse of several stones. Examination of the vaults indicated that they had not distorted, but much of their mortar had been washed out. It was decided to rake out and repoint all joints including those where mortar was still in place. As the joints between the stones were large it was possible to repack these, and where stone was missing it was replaced. Vaults were then treated with SIKA waterproof render.

Structural steel frame

Dimensional stability was considered to be very important for compatibility of the new structural frame with both the existing facade and the new stone cladding. For this reason alone a structural steel frame was justified. Furthermore, structural steel was expected to be quicker to construct than a concrete frame and would allow the use of composite metal deck flooring in many areas, so minimising the structural floor thickness and self weight. As the floor to ceiling heights were set by existing window heights within the facade, and as substantial depths were also required for smoke reservoirs, floor thickness was an important consideration.

In the event, there was so much dimensional inconsistency in the facade that there was very little repetition in the steelwork and with the beams and columns in external walls all needing to be encased in concrete for protection, there was probably no saving in time over a concrete frame during construction. The steel frame did however, allow ready fixing of the facade restraint subframes.

Furthermore, there were problems in constructing the metal decking in accordance with BS 5050 Part 4. In some areas inadequate propping led to construction stage deflections greater than permitted in the British Standard, requiring the installation of additional trimmer beams to strengthen the floor.

Suspended reinforced concrete slabs

In the central mall the architect required an open area with as few columns as possible. In order to maintain the depth of the smoke reservoir, the slab could not cantilever over surrounded steel beams and so was designed as a reinforced concrete ring spanning between these beams. Extensive grillage analysis was necessary to determine reinforcement requirements (Fig 7.8).

As the architect was unhappy with the finishes of fire protection treatments available for feature steelwork, the slab was designed to be propped by the legs of the scenic lift under normal conditions but to be supported by surrounded steelwork in the event of a fire. In this way, no fire protection was necessary for any of the feature steelwork in the public areas.

Steelwork to atrium and mall roofs

The client required a scenic lift, selecting steelwork detailed to a high standard. Circular hollow sections were used with solid pieces welded in at the joints to provide stress transfer between diagonals, horizontals and verticals, while 16mm diameter round bar with threaded ends was used for diagonals. All joints were made using fork ends and 20 or 40mm diameter pins secured by cover plates.

Roof glazing

The glazing lies outside the primary roof structure, with the roof lantern structure supported on the lift steelwork. It is not entirely satisfactory as, at changes in direction, the glazing flashing required a specific width for fixing, thus setting the width of glazing elements at many locations in the octagonal lantern. These glazing fittings were wider than structurally necessary and are much more visible than was intended or desirable (Fig 7.9).

On the straight mall roof there are fewer corner flashings – the glazing bars are much narrower and the glazing is less obtrusive. External cleaning of glazing is carried out from the roof while mobile platforms erected from the floor are used inside.

Stone cladding to new elevations

Bath stone is a very soft material. It is very consistent and easily worked to provide very intricate details, but it does deteriorate over the years. There has thus been continuous work for stonemasons in Bath for the past 250 years, both in building new buildings and in restoring and repairing old ones. There is

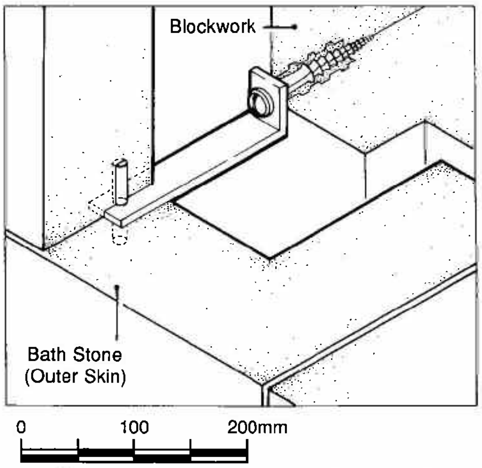


Fig 7.10 Isometric of fixing for stone cladding on front facade

Fig 7.11 Stonework repair in stonemason's workshop

enormous experience and expertise in the stonemasons' design offices and workshops, and on site the standard of work is very high. Extensive stone refurbishment to the existing facade, the construction of the new stone facade facing St Michael's Place and the carving of the replacement Corinthian column heads was carried by G V Williams, stonemasons of Bath, to the architects' demanding designs. This required the deployment of the great traditional skills of the stonemason allied to the modern technology of stainless steel engineering in order to transfer the stability provided by the temporary shoring on to the newly erected structural steel frame of the building.

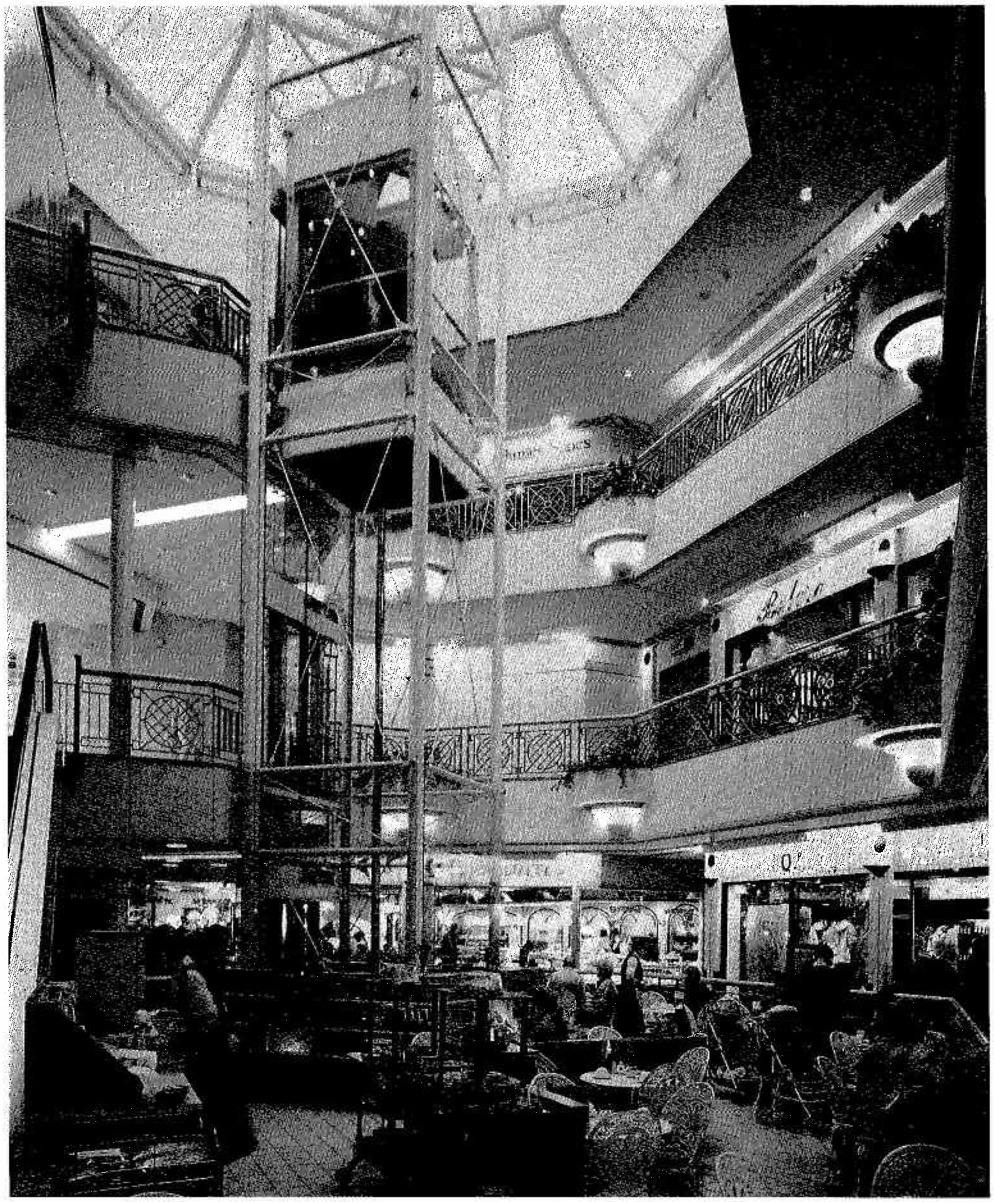


Fig 7.12 Finished interior of Colonnades development

All new elevations were clad with Bath stone using a traditional ashlar on main elevations and an improved rangework finish on rear elevations, thus facilitating a more economic use of the stone. The 100mm thick cladding is supported vertically by the new structure at ground or roof level and in a limited area on stainless steel angles. Horizontal support is provided by 200mm thick block walls infilled between the structural columns and beams. Every stone has at least one stainless steel cramp plugged and screwed to the new structure (Fig 7.10). All steelwork on the external elevations is encased in concrete and the cramps can be plugged and screwed directly into this. In their workshops the stonemasons used traditional techniques to produce new columns and column heads for the main entrance to match the columns produced for Baldwin 200 years ago (Fig 7.11).

The Colonnades – Building services and environmental design

The Colonnades is a medium sized shop and office development aimed at providing an outlet for mainly independent speciality retailers. Thirty six small and medium sized retail units on three levels are gathered around a common mall which itself provides circulation space and additional restaurant accommodation (Fig 7.12). A management suite on

Fig 7.13 Ducted ventilation system at lower ground floor level

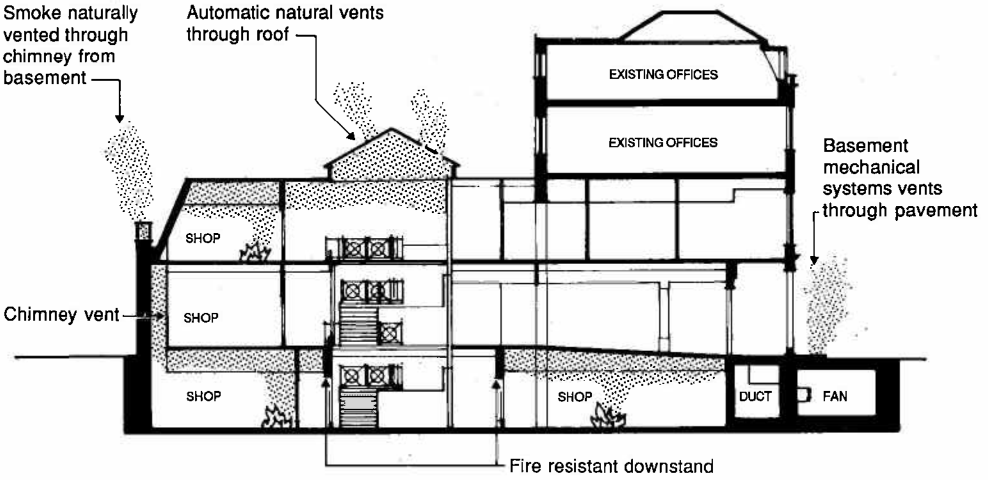


Fig 7.14 Proposals for fire engineering scheme – N/S section

the first floor serves the centre's administrative staff and two floors of office accommodation above have been leased back to Bath City Council. Mechanical and electrical services have therefore been designed to serve three essentially different environments, namely the retail units, the mall and the office areas .

Ventilation, heating and fire engineering requirements

The mall was conceived as an external space, but providing shelter from the worst extremes of the British weather. A high glazed roof provides protection from wind, rain and snow, but still allows large amounts of daylight in and provides shoppers with a contact with the outside. Open entrances provide natural ventilation, promoted by opening roof vents which in summer help to reduce peak temperatures, particularly at the upper level. In addition, the form of the building and its interior gives shade from high solar gains and high radiant temperatures during the summer months.

No heating is provided in the mall – gains from the shops, lighting, and the people help to raise the temperature a little above outdoor ambient. It was estimated that in winter temperatures would rise to 6–7°C above ambient and in summer 2–3°C above ambient. A small amount of ventilation air is introduced via a ducted system to the lower ground floor where, due to the form of the interior, natural ventilation could not be relied upon to produce an acceptable environment (Fig 7.13). While low air temperatures increase the risk of condensation damage to the fabric of the building, the high ventilation rates achieved can more than compensate for this.

In a space of this nature control of smoke and fire was an important factor in the design and execution of the mechanical and electrical services and this became an integral part of the ventilation strategy (Fig 7.14). Further discussion of the fire engineering design may be found in Patterns 2 (Ref 7.1).

Electrical services

Retail units were designed as a shell only, with facilities available in each for connection to the drainage system, water and electricity mains, and BT. In addition each unit was sprinklered in keeping with the overall fire engineering strategy, and linked to the development's addressable firm alarm system. Retailers were then free to fit out the units to their own specification and detailing, but within the rules set out in the tenants handbook, so ensuring that fitting out was compatible not only with the architect's concepts, but also with the overall engineering strategy (and in particular that of fire engineering) of the development. A system of drawings approval and inspections was established to ensure tenants conformed with these rules.

The second and third floors are occupied by offices which have subsequently been leased back to Bath City Council. They are served independently of the shopping centre and have been designed to a fairly basic specification to satisfy heating, lighting, power, telecommunications, water and sanitary requirements. It was, however, necessary to integrate the fire alarm system with that of the shopping mall giving a sequenced response depending upon the source or sources of the alarm.

Completion of project

The installation of the building services – the air ducts, the fire alarm system, the colonnade lighting systems, and the provision of services to each shop unit – followed directly behind the completion of the building shell. This was in turn followed by the addition of the elaborate finishes to the public malls, the water features and the glass lifts and escalators (Fig 7.15).

Fitting out of the three levels of shops started in August 1988 and in October 1988, just over two years after the fire and less than three years after the building had been acquired by the developers, the new building was open to the public.

Postscript

The success of a development such as the Colonnades depends largely on whether it satisfies a need within the local community. Even a development which has involved careful restoration of a listed facade and the incorporation of the facility itself into the existing urban fabric will have its critics when erected in a heritage city such as Bath. However, there has also been some criticism by the shop tenants of the open environment of the public mall. This has centred on the low temperatures and draughts in the winter despite the fact that the concept genuinely espouses the benefits for the rest of the year of a 'natural' environment in the mall. This criticism may indicate a general desire by tenants around such a mall for more closely controlled and heated internal public spaces – a desire probably at variance with the comfort of the shopper. Certainly the exclusion of draughts within mall areas is an important element in obtaining a tolerant internal winter climate.

The physics of a public mall is naturally quite complex and in recognition of this temperatures in the Colonnades have been measured at various times of the year in order to check earlier predictions of the environment. The results are tabulated below. (Table 7.1).

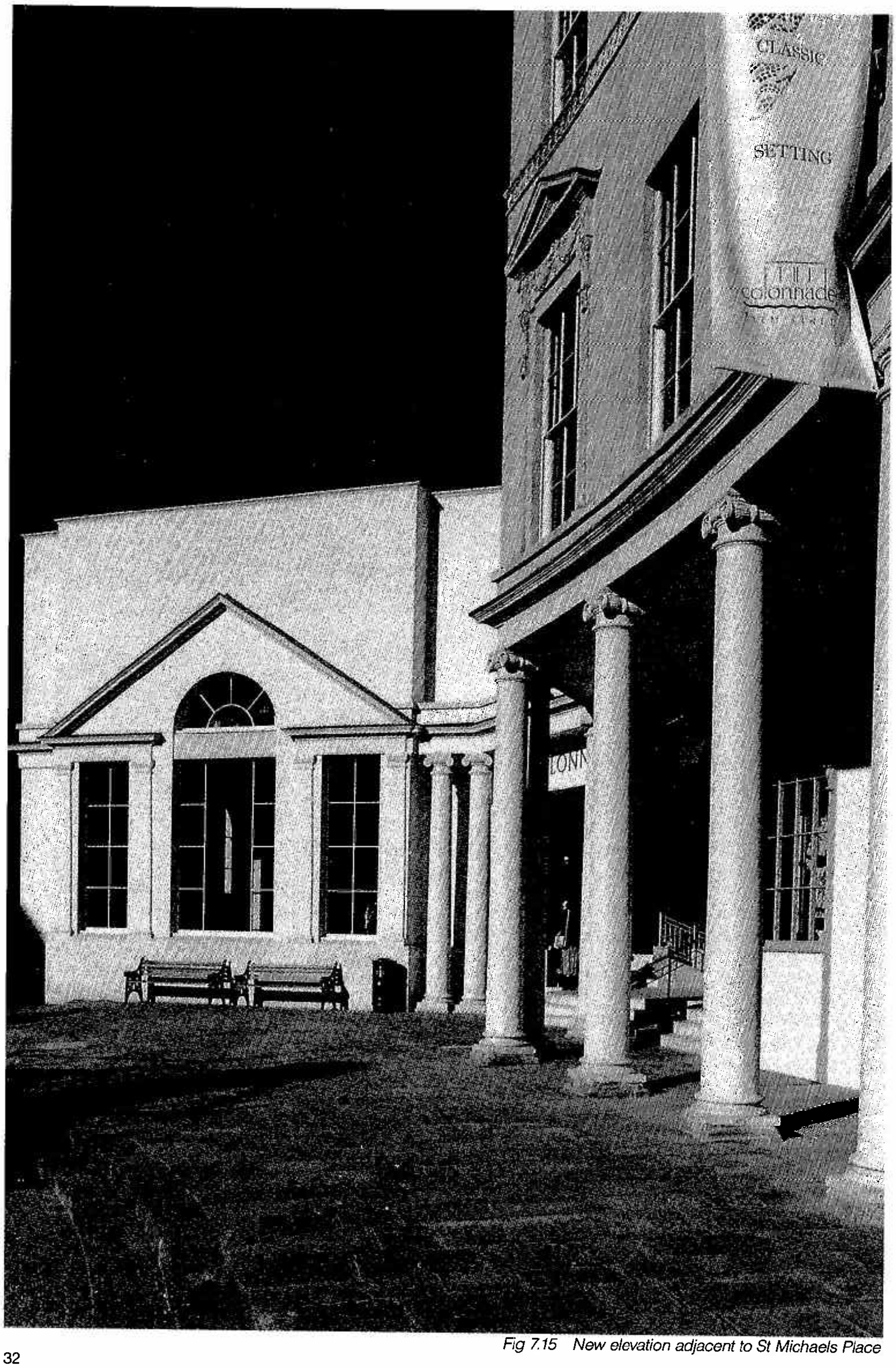


Fig 7.15 New elevation adjacent to St Michaels Place

	3 November 1988	2 June 1989
Outdoor Ambient	6.6°C	27.5°C (28.2°C in sun)
First Floor Mall	15.5°C	27.8°C
Ground Floor Mall	10.5°C	27.9°C
Lower Ground Floor Mall	10.8°C	26.6°C

Table 7.1 Sample temperatures showing seasonal variation within Colonnades development.

The table shows that in winter temperatures were between 3.9 and 8.9°C above ambient and in summer a degree or so below ambient in the lower mall and, by reason of the large high reservoir over the mall beneath the lantern, not much in excess of ambient at the first floor level. Both winter and summer temperature readings were taken at about noon so clearly temperature readings are in line with those estimated and actually set during the development of the design.

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References

7.1 Green M. 'Fire Engineering' Patterns 2 p9 Buro Happold 1988.

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