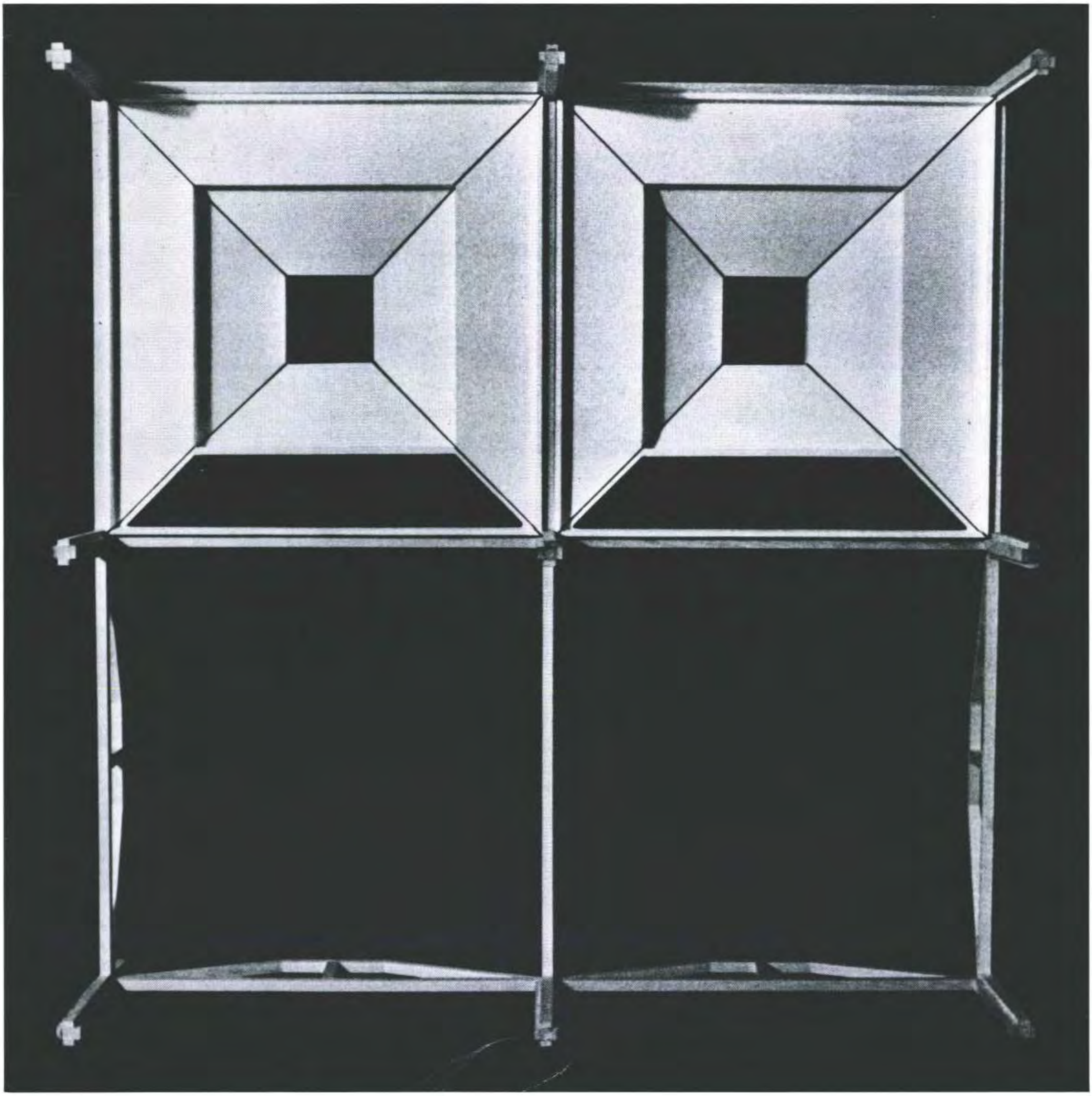
# THE ARUP JOURNAL

SEPTEMBER 1979



# THE ARUP JOURNAL

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Contents



Front and back covers: Models of Gateway House structural units (*Photos:* Arup Associates)

# Gateway House

**Designers: Arup Associates Group 2**

### The client

*Gateway* is the trade mark of one of Arups principal raw materials: tracing paper. It is also one of the trade marks of Wiggins Teape, and the name of their new headquarters at Basingstoke.

### History

Many firms based in London have looked into the idea of moving out of town, but the attraction of lower running costs, less time spent travelling and more pleasant working conditions, have to be balanced against the disadvantages of no longer being in the centre of things, particularly a specialized labour market.

Wiggins Teape had been in London for over 200 years. After the War they moved into the first new post-war office building immediately behind St. Paul's Cathedral, and later acquired the freehold. In the early 1970s, the property boom made many companies reassess their assets and Wiggins Teape were sitting on a massive one in the middle of the City.

Financially, the case was made, but a condition of the extremely profitable sale of its City building was immediate vacant possession for the new owner. So Wiggins Teape had to find an out-of-town location for a new tailor-made building with nearby vacant office space that it could occupy while the new Head Office was being built. This was possible on a new 'business' estate known as the Eastrop Estate at Basingstoke.

Wiggins Teape came to us in 1973 for a building of about 20,000 m², and parking for about 400 cars. The site is about 0.75 km from Basingstoke's new shopping centre, about 1.5 ha in area and on a south-facing slope of about 1 in 10.

### Design evolution

The design of the building has been generated out of three main sets of considerations. These are: (1) The specific requirements of the brief (2) The general characteristics of the site (3) A set of intentions with regard to the office space which have been developed in consultation with the client.

### Requirements of the brief

The part of the brief most relevant to the initial design stages stated that:

'Wiggins Teape is anxious to secure an efficient, low-cost-in-use building offering flexibility of utilization and internal planning with a combination of unobstructed open space and space suitable for a mix of open office landscape and private office compartmentation styles of layout planning. The design, therefore, should resolve and satisfy the multifarious physical, philosophical and engineering requirements that any typical organization performing a full range of office functions may reasonably be expected to have, and it should also permit a reasonable subdivision of the space into separate tenancies'.

### Characteristics of the site

The fact that there are pleasant unobstructed views to the south suggested that most of the offices should be orientated in this direction. This is reinforced by the quite steep southwards slope of the site. Since no further building can take place to the south, it was unnecessary to build a very tall building in order to be sure of clear views. Such a tall building would have seriously obstructed the views from those to be built higher up the slope to the north.

The car parks have been designed to fit under the building, and access to them is gained by using the natural slope of the site.

### Intentions with regard to the office space

Two broad aims guided the evolution of the design of the office spaces. These were to accept the variety of uses of the offices and their differing spatial requirements, and to take advantage of the opportunities offered by the out-of-town site. These aims determined more specific intentions concerning the office spaces.

### Different types of office

Fundamental considerations were raised by the need to accommodate both large open offices and small closed offices in unpredictable and changing proportions. The brief makes it clear that the office spaces were not to be suitable only as open offices, nor only as small separate offices.

The intention has been to include within the building a range of office spaces, all of which could successfully be used as open offices with or without associated small enclosed offices, and some of which would be suitable for a much larger measure of sub-division. More specifically, this implies various combinations of office depth and outlook, and an articulation within the open offices of the larger spatial module of the structural bays of the building. The unit should not be so large that it could not be clearly apprehended from within the open offices.

Several factors combined to suggest that the building should be built up by the repetition of standard units. Such a method served the interests of flexibility in use, consistency of appearance, and speed and economy of construction. However, the spaces enclosed by the units needed to vary, not only in dimension as indicated earlier, but also in quality. Thus one of the criteria for the design of the standard structural units was that they should accommodate and enhance variations of form, finish and lighting.

### Special areas

Within the continuum of the office spaces there was a varying need for conference rooms, and areas for relaxation and meetings. It was intended to include areas within the total office space which would be especially suitable for such uses, although they would also serve as normal offices if that were the sole requirement.

### Views and daylight

One of the advantages of the out-of-town site is that it offers unobstructed and pleasant views. It has been a clear intention to make such a view available to most of the inhabitants of the building without thrusting it monotonously upon them. This has important implications for the design of open offices, since it limits their depth. A related intention has been that the offices should, as far as possible, have natural lighting both because it is economical and because artificial lighting cannot give the changing effects of natural light.

### External open space

Efforts have been made to make pleasant out-of-door areas available to all those who work in the building, on the basis both that it is

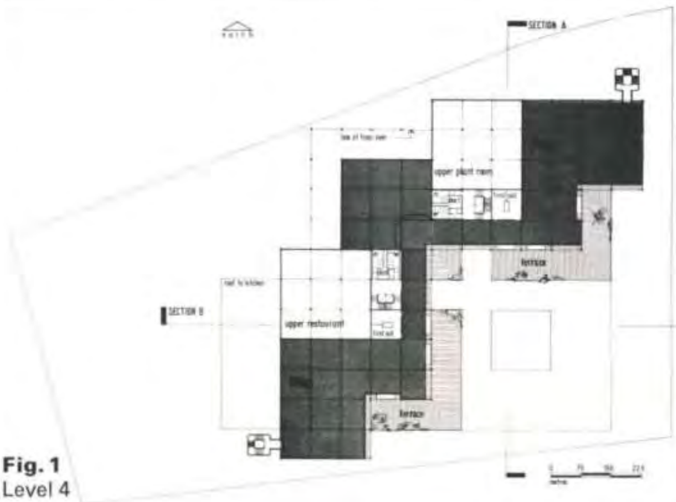



**Fig. 1**
Level 4

**Fig. 2**
Site plan


**Fig. 3**
Level 3

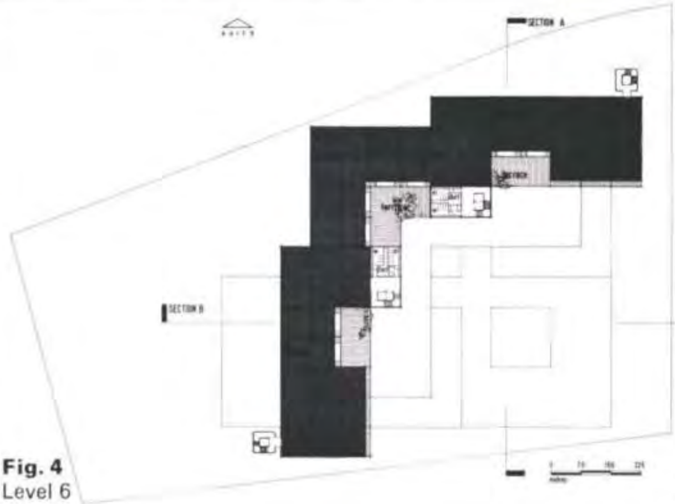



**Fig. 4**
Level 6

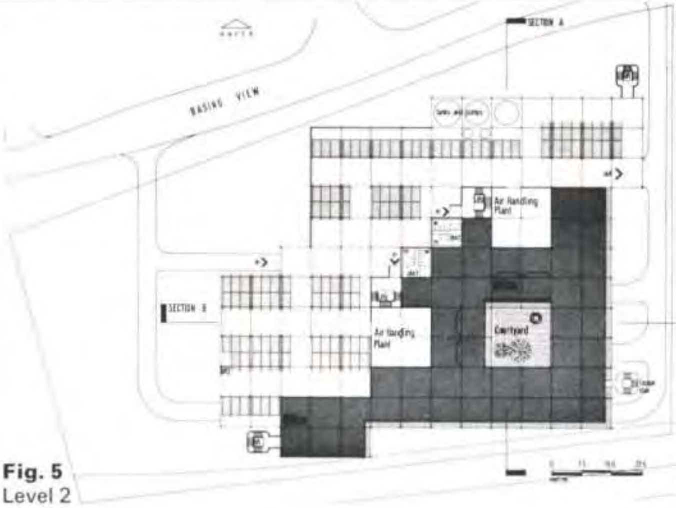



**Fig. 5**
Level 2


**Fig. 6**
Level 5

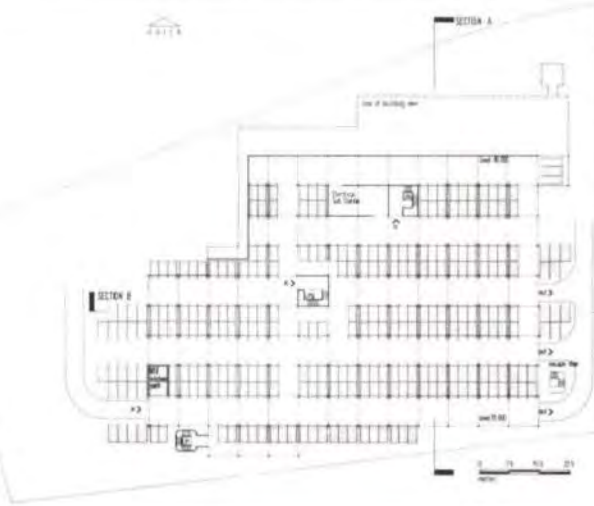



**Fig. 7**
Level 1

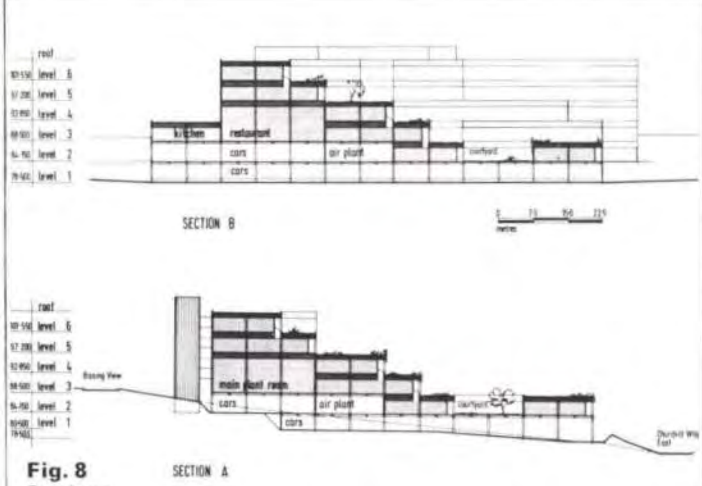



**Fig. 8**
Sections

sometimes desirable actually to go outside from your office, and that the knowledge that it is possible to do so banishes any feeling of being 'cooped up'. So the terraces and courtyard have been extensively landscaped in such a way as to offer considerable variety of outlook from different offices on all levels. Trees, bushes, grass, paving, seats, rocks, pebbles and water have all been used. Areas of the site not occupied by the building have also been densely landscaped with semi-mature trees.

### General layout of the building

The basic form of the building is that of an L whose two wings surround a space to the south-east. The offices step down in terraces around this space, and at the lowest level are enclosed around a courtyard. The main entrance occurs at the intersection of the two wings, and from it the main lift cores associated with each wing are visible. The entrance area also penetrates to the front of the building, and allows some idea of the arrangement of the offices around the external space to be apprehended on entering.

The restaurant and plant room have been designed as double height spaces on the western and northern faces of the building, on each side of the main entrance.

### The structure

The column centres were required at 7.5 m in both directions to incorporate a 1.5 m planning grid, car parking grid (at lower levels) and office depths from glazed elevations within acceptable limits for daylighting and environmental control. It was also necessary to incorporate a services void, to house the air-conditioning and other services, with a structural ceiling to allow maintenance without disturbing the offices.

The solution was a precast concrete 'pyramid', made (off-site) in four identical $3\frac{1}{2}$ tonne quadrants, leaning together and jointed on the diagonals. On-site casting of the pyramid units in one piece was investigated, but rejected because of serious lack of space. The resulting 7.5 m square unit was bounded on all four sides by a precast lattice structure which, together with the 'neck' of the pyramid units, supported an in situ two-way spanning floor slab, cast on *Holorib* steel decking used as permanent formwork. The 'pyramid' units were cast with a very high standard smooth soffit, exposed within the offices, and finished with a lightly textured paint.

The shape of the ceiling is partly determined by the structural requirement of providing support to the floor slab above, the thrust from this support being carried down the diagonal ceiling member and anchored in the columns; edge and corner restraint is provided by the bottom chord of the edge truss. The critical connection of these units is achieved by an in situ octagonal void column which stitches the ends of the trusses and ceiling units together.

The floor loadings are 5 kN/m² for the offices, including partitions, and 6.5 kN/m² for the terraces which includes a 4 kN/m² soil loading. Concrete strengths for both precast and in situ were 40 N/mm².

### Foundations

The site strata are chalk of fairly consistent quality of the Upper chalk series. Trial pits revealed some areas of redeposited chalk at the lower end of the site. Pad footings were designed to support the structure with bearing pressures around 400 kN/m². The footings were taken to depths of 2.5 m in the poorer chalk areas to found in firmer strata. Retaining walls were avoided by forming steep chalk batters which were bridged over around the perimeter.

**Figs. 9-11**
Models showing the structural progression

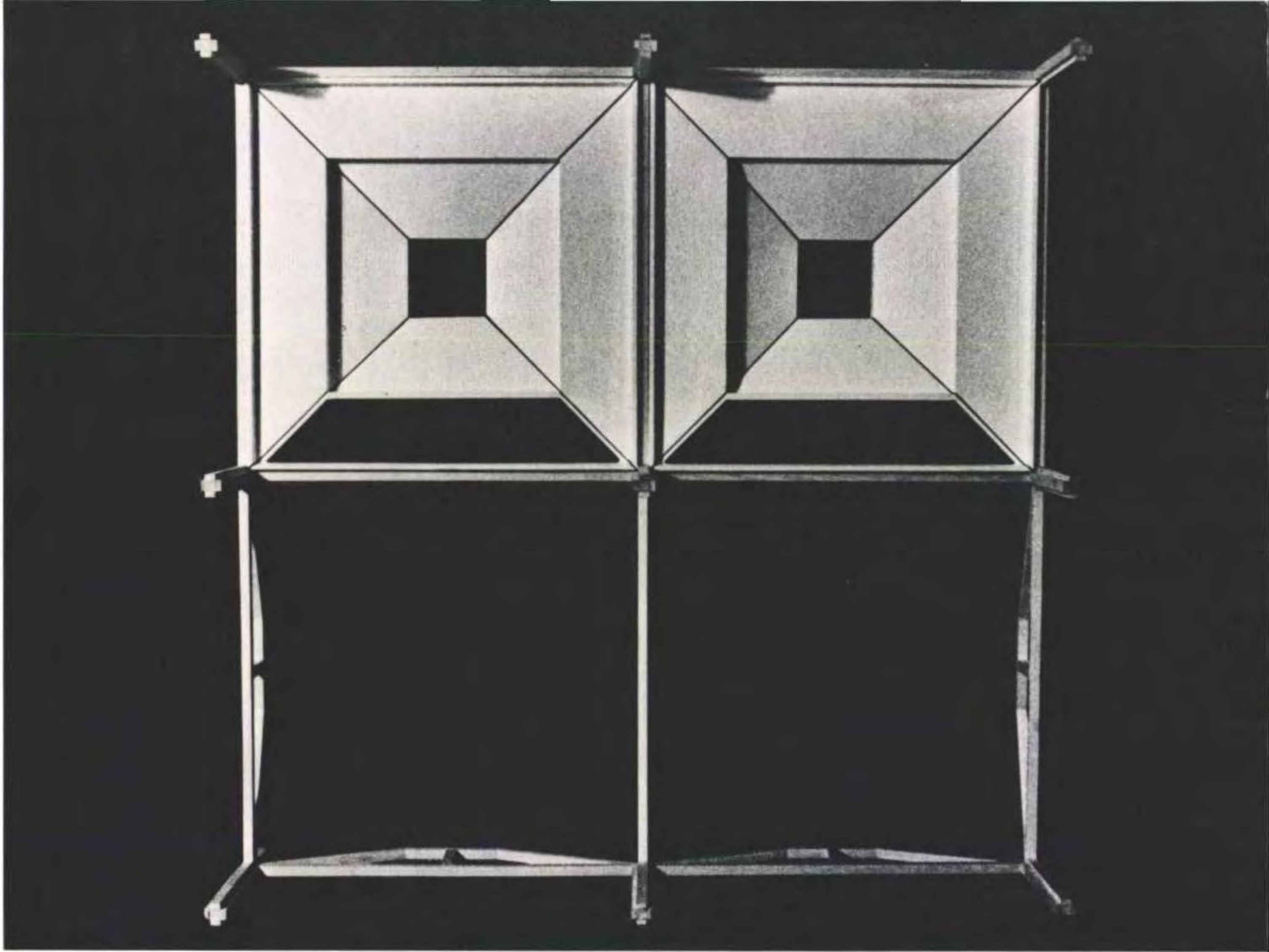


**Fig. 12**
Structural unit looking up

**Fig. 13**
Structural unit looking down

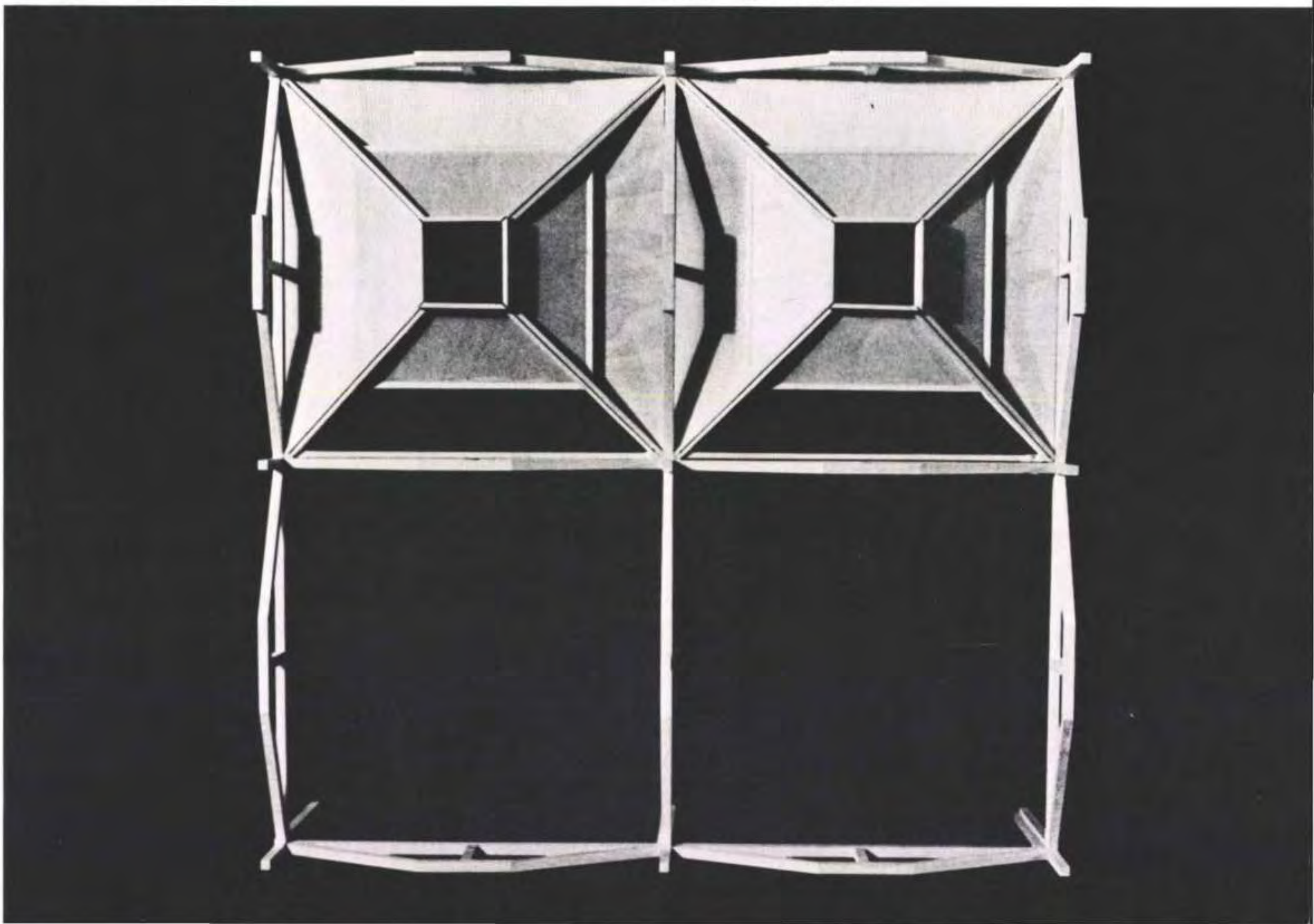
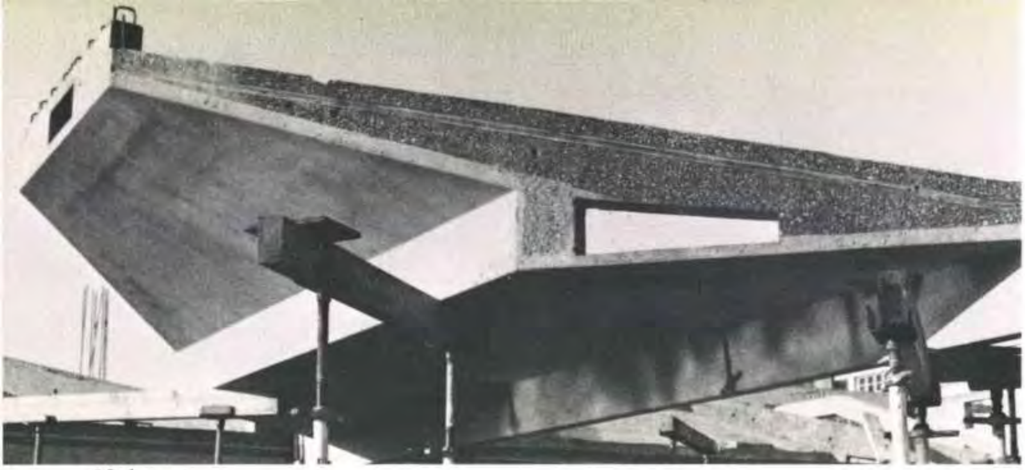


**Fig. 14**
Precast quadrant

**Figs. 15-16**
Erection of pyramids

**Fig. 17**
Structural pyramids looking down

**Fig. 18**
Structural pyramids looking up



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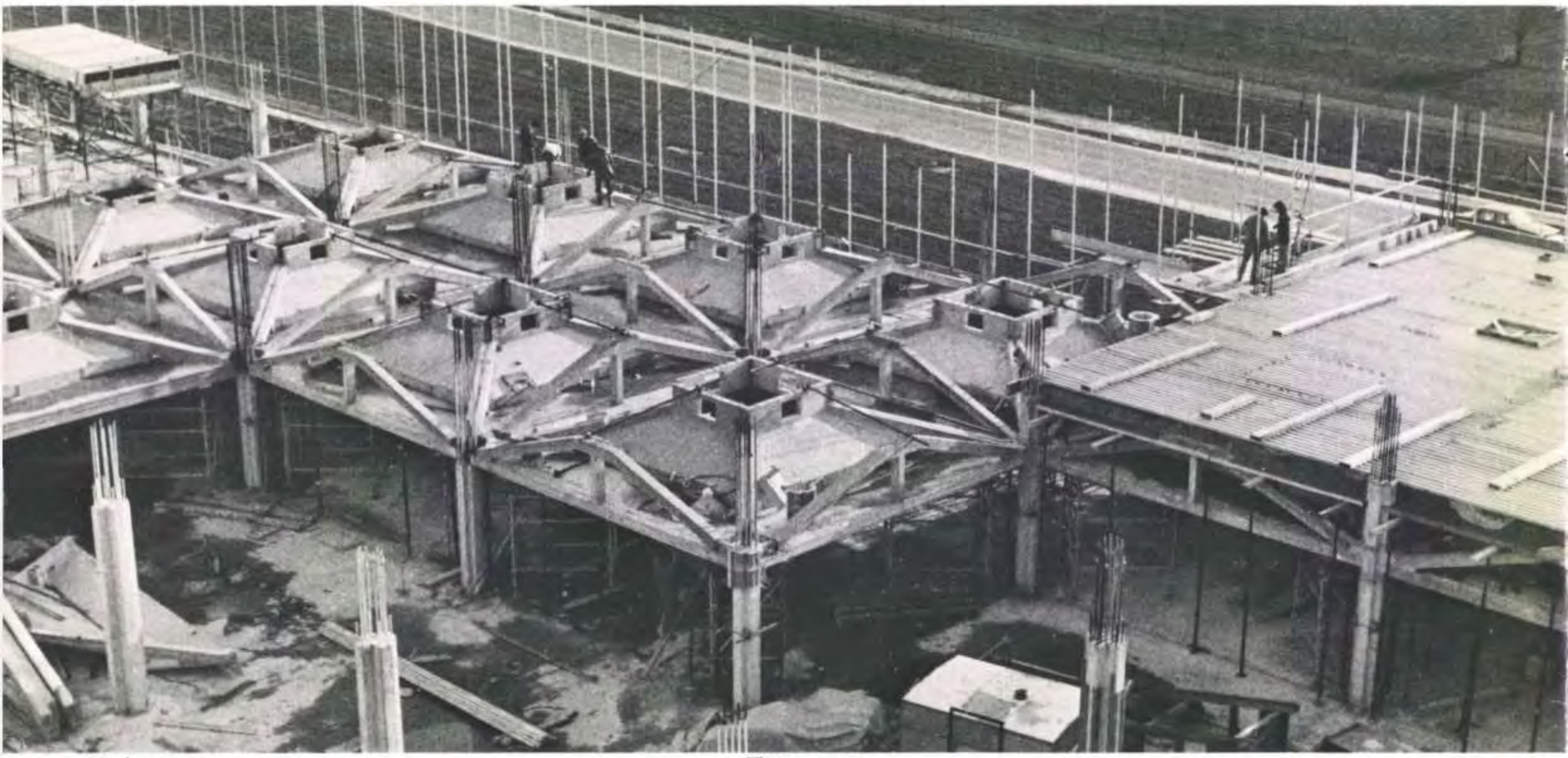

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▼ 16

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## Air-conditioning

The original brief stated that 'all year round air-conditioning incorporating zone separation, heat reclaim, limited individual control and efficient central control facilities' was required. The building was designed during the worst period of the 1974 energy crisis and this experience increased the client's and the design team's awareness of the need to design an energy-conscious building.

The design of the building fabric can make huge differences to the initial cost and running costs of an air-conditioned system. The aim, therefore, was to produce a thermally stable building and the consequent economy by reducing the loads imposed on the system, the major contributing factors being:

(1) Limited glazed areas which also ensure good daylighting of the space and provide a reasonable view of the outside world for the occupier; the provision of structural overhangs to shade the glazing and the use of blinds to reduce the solar gain

(2) The building fabric insulated to a high degree to counter winter losses and summer gains

(3) A structure having a high thermal capacity

(4) Minimum heat gain from artificial lighting by designing to a reasonable level and providing both master and local switching control.

A basic system for air-conditioning the office spaces using induction units was proposed. The main advantages of this system are that relatively small duct sizes are needed as a result of reducing the air supply by the use of secondary cooling and high velocity air design. The return air duct system is also reduced in size. Since a relatively small amount of air must be conditioned, there is a reduction in the size of the central air handling apparatus and therefore a saving in the installed building cooling capacity and plant horsepowers.

For the purpose of zoning, the building was divided into two vertical sections by a plane running diagonally across the plan and into two horizontal layers by a plane taken through the building at fifth floor level.

Thus four air plants were provided to serve the offices, two at roof level, and two plants at Level 2. The distribution of air and water from these plants was via vertical service cores formed within the toilet areas with branches taken into the voids. The induction units were located beneath the perimeter glazing, one in each 1.5 m module and capable of serving a bay depth of 7 m.

Each unit was provided with a control valve and thermostats serving one, two or up to a maximum of three units, giving the facility of limited individual room temperature control.

The air plants comprised fresh air and return air connections into a mixing chamber, roll filter, humidifier, cooling coil and centrifugal supply air fan and were connected through a silencer to a plenum chamber from which the various zone ducts, complete with zone heater battery, were taken to serve a particular facade or internal space.

The air extracted from the office areas was pulled through the lighting fittings in the suspended ceiling unit and returned to the plant for recirculation or exhausted to atmosphere by an axial floor fan.

Where the depths of floors were beyond the scope of induction units, the conditioned air was supplied through grilles located in the side of the ceiling unit via high velocity ducts to constant volume terminal units and heaters located in the services void local to the area being served.

### Conference areas within office spaces

In order to cope with the special requirements of conference rooms, two small air handling plants were located in the void adjacent to a service core to provide for the needs of conference rooms within the two L-shaped wings of the building at each level. These plants were connected to spine ducts, to which flexible connections could be made to diffusers serving conference rooms in the required positions. The system allows freedom in positioning and moving conference rooms, though the number in each wing is limited by the capacity of the plant. The plants can be switched on from the conference rooms when required, otherwise the spaces are conditioned by the normal induction system.

### Kitchen

The kitchen was provided with a system of extract ventilation, sized to suit the load imposed by the kitchen equipment, the make-up air being drawn from the restaurant, supplemented by a separate tempered air supply system arranged to introduce air around the main cooking island sites. The temperature of the supplementary air supply may be locally controlled in the kitchen area.

### Toilet ventilation

All internal toilet areas were mechanically ventilated to provide a minimum of six air changes per hour and heated by inbuilt fan convectors.

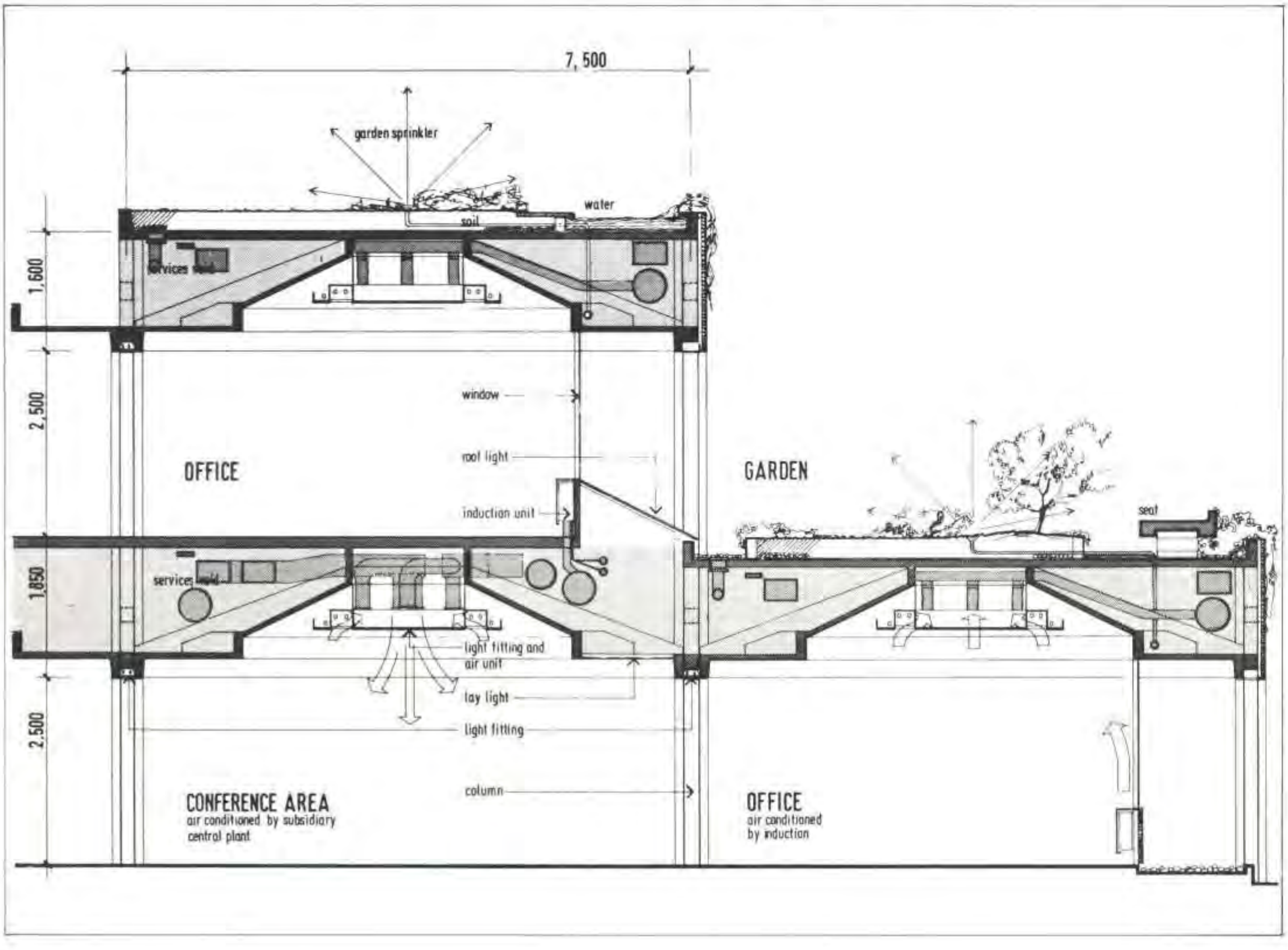


**Fig. 19**
Section through office structure showing services

### Computer suite

The computer suite was provided with a separate air-conditioning system which comprised two air handling units – one providing sensible cooling and the other providing dehumidification – two reciprocating chiller units with duplicate chilled water and condenser water pumps all located in an adjacent plant room. The cooling towers were situated at roof level alongside those which serve the main office air-conditioning system. The supply air was ducted into a ventilated ceiling space and the return air was drawn through grilles in the suspended floor and ducted back to the air plant.

### Main plant room

The main plant room was designed to be a feature of the building. It is fully glazed and, being located adjacent to the building entrance, is on view to both visitors and the general public. Housed within the plant room are three heating boilers, two chiller units, two HWS calorifiers, cold water booster set, hose reel water booster set and duplicate sets of heating pumps, chilled water and condenser water pumps. All pumps are mounted on a steel gantry at mezzanine level.

### Control and monitoring

A pneumatic system of automatic temperature controls was chosen for this installation, the air lines from the central air compressor plant being distributed through the service cores and voids to serve all plant rooms and induction unit control valves.

A supervisory desk console was located in the main plant room linked to eight outstations in the various air handling plant room control panels. The console contains power units for the complete scheme and a scanning unit to provide automatic monitoring of all remote critical alarm and start/stop points. A strip printer unit is incorporated into the console which indicates date, time, point number and type of alarm with provision for scanning of alarm and status. In addition to the facilities provided for the mechanical installation, the console has 36 hours run meters for lighting circuits, boiler and refrigeration machines, 28 lighting circuit switches plus lift, fire and security alarm.

### The energy consumption report

By the beginning of 1974 when the building was in its later stages of design, the client became keen to obtain an estimate of running costs and energy consumption for the building compared with other similar buildings. They were also interested in the cost comparison and comfort levels of conditioned and non-conditioned offices.

At this time it was becoming increasingly obvious that future fuel supplies were unstable and therefore the report that Arups prepared to cover the previous matters also encompassed the evaluation of various fuels and standby facilities.

These were the main headings under which detailed discussions and calculations were carried out:

(1) A comparison of energy requirements between the Wiggins Teape offices and a typical good class modern air-conditioned office building

(2) Estimated energy consumption and costs for the Wiggins Teape offices

(3) Effect on the building if it was mechanically ventilated but not cooled

(4) Effect on the building if it was naturally ventilated

(5) Effect on electrical power failure – with and without standby generation

(6) Investigation into the use of various fuels for heating purposes.

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**Figs. 20-23**
Views of main plantroom

22 ▼

23 ▼

The results of the investigations for Items 1–4 are given in the following table:

**Table of energy consumption using gas as heating fuel**

| **Building type** | **A** | **B** | **C** | **D** | **E** |
|---|---|---|---|---|---|
| | Wiggins Teape Full air-conditioning to offices | Wiggins Teape Full air-conditioning installed but cooling plant switched off | Wiggins Teape Centrally heated in winter Mechanical ventilation to internal areas. Natural ventilation to perimeter areas by openable windows | Alternative Air-conditioned office building | Wiggins Teape Full air-conditioning to offices (eight-hour day comparison) |
| **Energy consumption** | | | | | |
| Gas unit/annum | 254,000 therms including catering | 220,000 therms including catering | 199,000 therms including catering | 694,000 therms including catering | 211,200 therms including catering |
| Electricity units/annum | 4,000,000 kWH | 3,100,000 kWH | 2,760,000 kWH | 6,470,000 kWH | 3,333,000 kWH |
| **Effect on comfort** Summer temperatures (Based on average yearly maximums for June/July/August, 13.00 hours to 16.00 hours possible 30 afternoons/year) | Temperature 22°C ± 1.7°C | Temperature 27°C – 30°C | Temperature 26.7°C – 29.4°C | Temperature 22°C ± 1.7°C | Temperature 22°C ± 1.7°C |
| | Humidity | Humidity | Humidity | Humidity | Humidity |
| | 50% ± 5% | No control | No control | 50% ± 5% | 50% ± 5% |

Obviously to make any comparison, certain assumptions have to be made. Those made in this energy report were as follows:

**Column A:**

Lighting at 80% full load during office hours.

Office hours: 10-hour day (8.00 a.m. to 6.00 p.m.).

Air conditioning plant operational for 14 hours/day.

No conditioning at nights and weekends but heating system would operate to maintain building at minimum 10°C via frost protection controls.

**Column B:**

Lighting, office hours and overnight/weekend frost protection, all as A.

Air-conditioning plant switched off (chillers, cooling towers, pumps) but air handling plant operational for 14 hours/day as A.

**Column C:**

Lighting, office hours and overnight/weekend frost protection, all as A.

Heating only for 30 weeks/year, 14 hours/day.

Heating system comprising radiators at perimeters and warm air to internal areas with return air system.

Double glazed windows as for A but with opening lights at regular intervals (i.e. a greater infiltration rate than a sealed building).

**Column D:**

The building referred to is in the City of London, a fully glazed tower block with no overhangs. The air-conditioning system comprises induction units to perimeters and an all-air system to internal zones (similar to the Wiggins Teape offices). The comfort conditions and runnings hours have been adjusted to be comparable with the Wiggins Teape offices.

**Column E:**

All elements as A except that the office hours are reduced to an eight-hour day (9 a.m. to 5 p.m.) and the air-conditioning plant is operational for 12 hours/day.

The energy consumption figures were calculated using the Ross Meriwether computer program which allowed for weather fluctuations and complete load profiles of all items of installed HVAC and electrical plant. Various computer runs were used to obtain the comparison study (A) and (D) with further detailed runs for the actual consumption figures for the Wiggins Teape offices.

The summer temperatures in column C were calculated from John Campbell's summertime internal temperature program and are based on opening windows giving an effect of three air changes/hour.

**Electrical power failure**

The report also discussed the effects on the building of electrical power failure. Obviously, the building would become unusable in this event, so two 500 kVA diesel oil fueled generator sets were installed. These machines, to be used only for emergencies, were sized for a reduced office load.

**Boiler fuel**

At the beginning of 1974, oil supplies became very much dependent on influences beyond the control of the oil companies which, in turn, brought about an increase in the demand for natural gas. However, for a time the Gas Board imposed a 100,000 therm/annum limit on new users so we were obliged to investigate the use of dual fuels or other possible sources such as LPG (butane or propane) and electricity.

However, the gas consumption limit was eventually lifted when the Frigg field came on tap and it was then agreed to proceed with single fueled gas boilers with short fan diluted flues. No tall chimneys were needed and oil storage was installed to serve only the standby electrical generators.

**Energy consumption – Postscript**

We have maintained a good relationship with Wiggins Teape since completion of the building, and their building manager has been helpful in supplying much feed-back information on the use of the services plant.

In comparison with our estimates of 254,000 therms and 4,000,000 kWH per annum consumption figures for the 10-hours office day, which are, in fact, the hours worked, the actual figures are as follows:

| Year | Gas | Electricity |
|---|---|---|
| 1977 | 180,000 therms | 3,092,500 kWH |
| 1978 | 158,000 therms | 3,068,600 kWH |
| 1979 | 175,000 therms (estimated for latter six months) | 3,094,850 kWH (estimated for latter six months) |

The plant and building generally are well maintained by a team of eight personnel and one supervisor. The team includes a carpenter, an electrician, a plumber, a mechanical fitter, an instrument mechanic and three assistants. The building services manager is very energy conscious and is constantly making manual adjustments to the controls system according to schedules in order to maintain conditions with the minimum usage of plant. During the recent winter, the chiller plant and associated pumps were not run for four months because they were able to use the free cooling facility afforded by the air handling system and maintained a minimum of 45% relative humidity by resetting the controls.

The boilers and air handling units were originally timed to start up together in the morning and it was found that because the boiler controls were on full by pass until the water temperature reached 60° C (to maintain high back end temperature on boilers), the air system tended to cool the building. The controls were reset to allow the boilers to start before the air handling units in order to overcome this problem, the delay varying according to the season.

During periods of night heating, the HWS calorifiers were being heated by water passing from the pumped heating circuit through the primaries to the calorifiers. This was corrected by the fitting of a relay in series with the secondary HWS pumps which prevent the control valves on the primary connections from opening when the pumps are not running.

The client is currently carrying out a survey on the use of lights and the possible reduction of lighting levels in some areas by changing lamps.

Void temperatures taken at night show that the building is retaining its heat. For instance, in the void under level 5, a temperature of 18° C was recorded with an external temperature of 7° C confirming the value of the insulation and roof gardens in adding thermal mass to the building.

Wiggins Teape are now looking for a 10% saving in energy throughout the whole of their manufacturing and administration premises and we have been requested to discuss with them the possibilities of achieving further economies at Basingstoke.

**Fig. 24**
Restaurant

**Fig. 25**
Office at Level 2

### Electrical services

The maximum total electrical demand for the whole building is approximately 2 MW. The supply of electricity is taken from the Southern Electricity Board's underground 11 kV network adjacent to the site, in the form of two 11 kV cable feeds onto a composite SEB/Wiggins Teape high voltage switchboard with the facility of connecting into either leg of the SEB 11 kV ring main distributors to achieve a secure supply.

The load of 2 MW was provided from three 1 MVA transformers giving a 50% standby capacity. The transformers are coupled to a primary main medium voltage cubicle switchboard from which each major load is served. The general distribution is by individual cable feeds to each floor with two submain distribution cubicle switchboards at load centre positions on each floor.

The breakdown of the electrical load requirements was made up as follows:

| | |
|---|---|
| General lighting | 520 kW |
| Office power | 160 |
| Kitchen power | 100 |
| HVAC auxiliary | 260 |
| HVAC main plant | 490 |
| Lifts | 70 |
| TOTAL | 1600 kW |

Assuming a 0.8 power factor, the maximum demand was approximately 2 MW.

Each level of the building is divided into four zones, with each zone served by its own separate lighting, emergency lighting and power distribution centres located within the vertical rising duct cores. In addition a supervisory control and indication and alarm system was installed in the main boiler control room to enable the plant supervisor to continuously monitor the conditions and security of all supplies to offices, main plant, fire and security alarm systems.

### Floor outlets

A system of floor outlets was required to provide easy and frequent access to power and telephone connections. The main electrical and telephones distribution work took the form of cable trunking and tray routes through the horizontal services void at each floor.

Each structural bay of the building is individually served by its own lighting and power sub-circuits, with the facility of locally extending those sub-circuits to suit any arrangement of lighting and power layouts within that bay. This was achieved by cabling to fixed terminal outlets from which 'plug in' extension connections to lighting fittings and socket outlets could be made as required.

The principle adopted for power outlet wiring consisted of each bay being served by a 30 amp 250 volt radial sub-circuit terminating at a 'plug in' junction box with the facility of extending on with premade radial cable connections to floor-mounted pedestal-type electrical power and telephone outlets.

Within each 7.5 m square bay, 60 conduit sleeves were cast vertically through the floor slab on a precise grid arrangement to provide a means of taking power and telephone cables from the void through the sleeves to terminate into demountable partitions and block walls or to pedestal floor outlets. A particular advantage of this facility was to always locate outlets within the confines of desks and keep circulation areas free of obstructions and trailing flexible leads.

As the entire electrical sub-circuit installation was carried out using mineral insulated cables, it was possible with the prior agreement of the Post Office telephone engineers to route electrical and telephone cables into the same floor outlet box with suitable segregation from live electrical terminals.

### Office lighting

Another interesting facet of the design developed from the integration of the lighting into the structural pyramid ceiling forming each 7.5 m square bay. It was a prerequisite that the lighting should complement and accentuate the internal spaces and be integrated with the structure and the air-conditioning system.

The structure offered two very clearly preferred locations for the lighting fitting, one located in the apex of each bay and another at the outer perimeter of the bays adjoining each other. These locations were developed into two separate details upon the same lighting fitting.

With a configuration of lighting fittings forming an inner square within a larger outer square and with the main source of illumination concentrated at the extreme outer edge of each bay, the initial lighting study indicated that to achieve a reasonably even distribution of light on the working surface would require a fitting to be designed to give a precisely directed 'batswing' light output, such that the fittings emitted their maximum downward light output at an angle of 25° to 35° to the vertical.

It was possible, using our own computer program ILLLH, to plot, on the point-by-point grid layout, the illuminance from the desired arrangement of fittings and transpose this information back into a specially designed fluorescent fitting to fulfil the required lighting output performance. The resultant fittings took the form of flush mounting, louvred, twin lamp, fluorescent units, each with an optically designed 'batswing' reflector and cross blade louvre and air handling slots. The two lamps were located one above the other within the reflector to achieve the pronounced 'batswing' distribution. A complete sample bay of fittings was erected on site for accurate measurements to be made of illuminance on both the horizontal and the vertical planes.

The results of these tests clearly indicated that it was possible to achieve the desired visual effect and the overall effect of the lighting not only co-ordinates well with the structure and spaces but also gives a pleasant degree of sparkle and modelling.

The fittings were installed with natural colour lamps and each group of fittings located in each bay could be locally controlled by cord pull switches and centrally master switched from the plant supervisor's control panel in the main plant room. Each sub-main lighting distribution board was connected to an hours run meter to enable the fitting maintenance to be carried out on a bulk cleaning and lamp replacement basis.

### Conclusion

The design for the building was approved by the client in December 1973, and was completed and occupied in September 1976. Although the landscaping of the terraces was firmly established by the time of handover, it is the maturing of this feature into its present lush profusion which has benefited the building most noticeably over the last three years. This has a great deal to do with Wiggins Teape's high standards of housekeeping which have developed an amenity into a showpiece. The roof gardens are even opened to the public once a year and the proceeds raised from the entrance fee given to a Gardeners' Charity.

Good housekeeping in a large building which houses nearly a thousand people at work does not happen by accident. It can be attributed directly to a small number of individuals who care enough to do something about it. This can be very clearly seen from the pictures of the main plantroom illustrating this article which were taken very recently after the plant has been running day and night for three years. The only difference between the photographs taken now and those taken just after handover is that a footmark left on the white floor in the original photographs has since been removed!

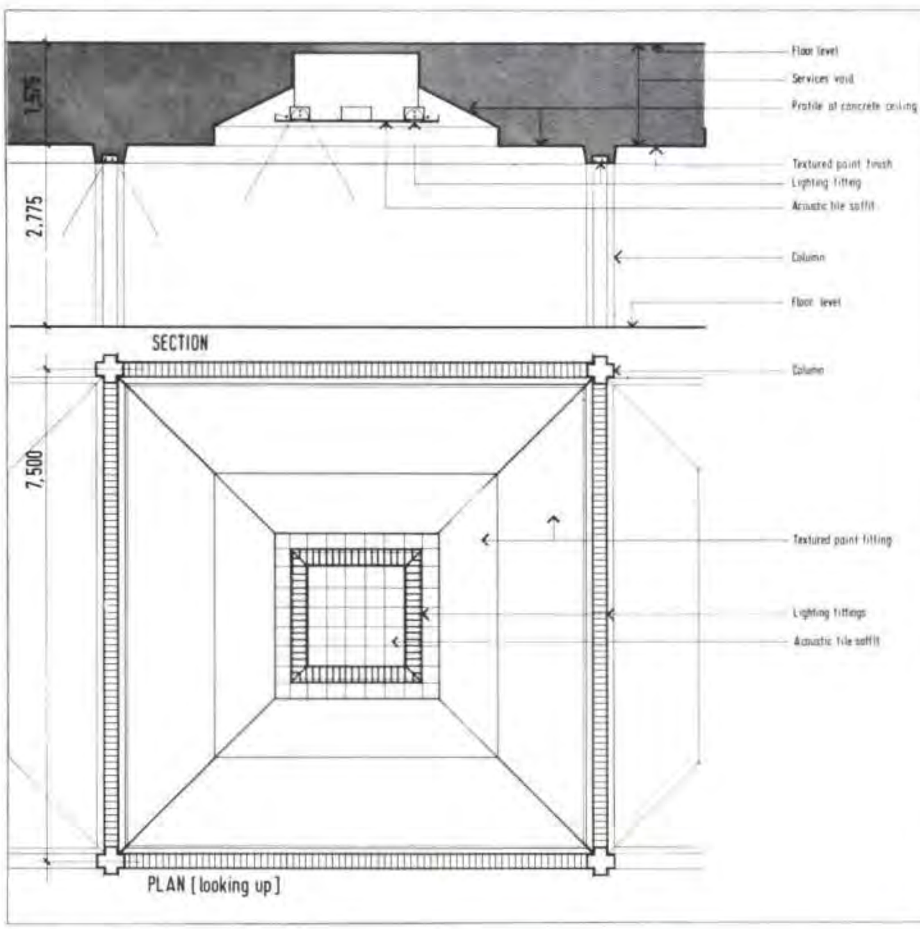


**Fig. 26**
Plan and section showing lighting arrangement


**Fig. 27**
An unexpected warning!

**Fig. 28 right**
The nest on the door closer

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**Fig. 29**
Roof garden

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**Fig. 30**
View from south west

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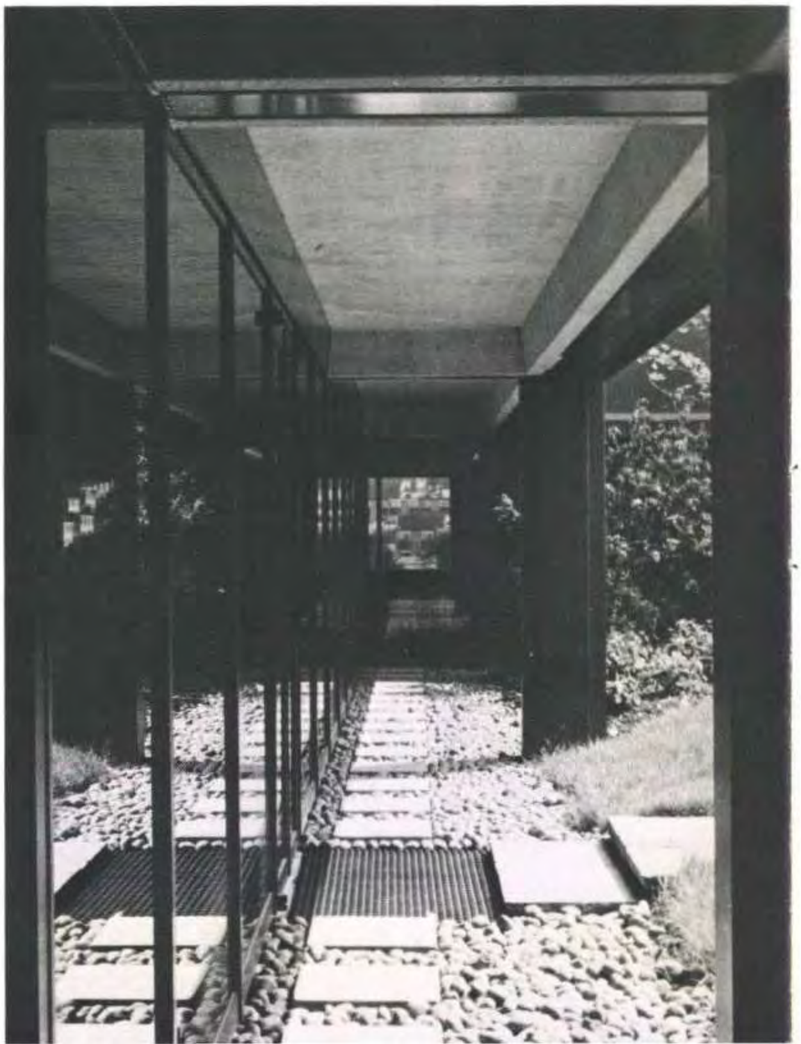
**Figs. 31-34**
Reflections

34



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**Figs. 35-40**
Views of roof gardens

39

38

40

**Gateway House Credits**

*Management contractor:*
Bovis Construction Ltd.

*Structure:*
Sindall Construction Ltd.

*Windows and cladding:*
Josef Gartner & Co.

*HVAC:*
Matthew Hall Mechanical Services

*Electrical and Plumbing:*
Haden Young Ltd.

*Terrace landscaping:*
Flower House Display Ltd.

*Landscape consultant:*
James Russell

*Photos:*
Arup Associates

# Wood Green Shopping City

**Architects: Sheppard, Robson & Partners**

John Melling

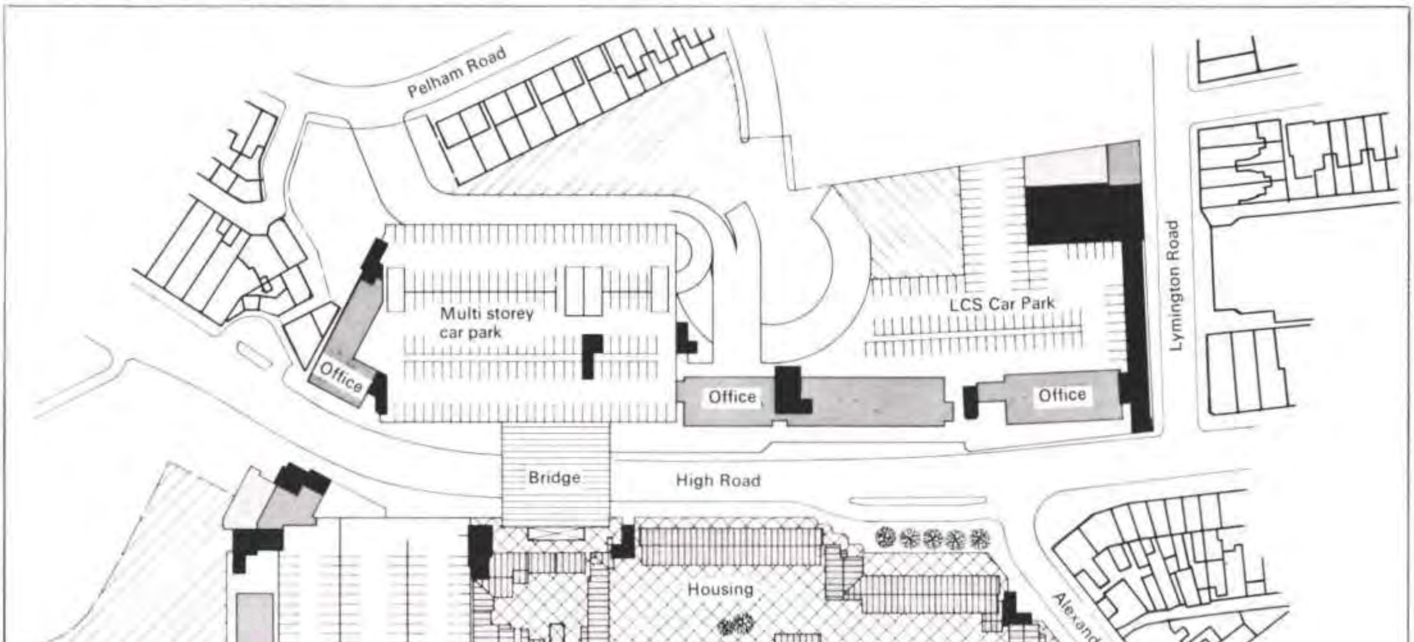
### Introduction

As long ago as the Middle Ages the village of Wood Green spanned the major northern route out of the City of London and was well-positioned even then to become one of the largest and most heavily populated shopping catchment areas of North London. In the 1860s the Great Northern Railway came to Wood Green attracting people, trade and housing development. This continual development has changed Wood Green from a semi-rural community to what is now an urban conurbation with the High Road as the focal point of what has been designated by the GLC as a regional shopping centre. It is well served by public transport, being a main bus route and having the Piccadilly Line beneath it with Turnpike Lane and Wood Green stations at either end. In 1965 the division of the area between the Boroughs of Hornsey, Wood Green and Tottenham was resolved by the inauguration of the London Borough of Haringey and the creation of the Haringey Central Area Team.

The Borough of Haringey obtained the freehold of a large area of land either side of the High Road, part of which had belonged to the Palace Gates Railway, and sought proposals from possible development partners. The Electricity Supply Nominees Ltd. (ESN) who are the pension fund to the electricity supply industry together with their professional advisers, Richard Ellis, Sheppard Robson, Gardiner & Theobald and ourselves, submitted a scheme which was accepted by the Borough. This stage was reached in 1970 and ESN became development partners with the London Borough of Haringey.

**Fig. 1**
Wood Green: Model of complete complex (*Photo:* courtesy of the architects)

**Fig. 2**
Site plan



### The scheme

The scheme has been constructed in three phases and comprises two levels of shopping, one at ground and the other at first floor, straggling either side of the High Road. There is a total area of 44,000 m² retail floor space which is broken down into 108 shopping units of varying sizes. Large units have already been taken by D. H. Evans, C & A Modes, W. H. Smith and many other well-known companies are, or soon will be, trading there. Adjacent to Phase 1, the London Co-operative Store have redeveloped and their new store is integrated within the whole development, having been constructed at the same time as Phase 1. Although there are some shops facing directly onto the High Road the majority open onto enclosed shopping malls which are fully air-conditioned. It is therefore possible to do away with normal shop fronts and allow the shops to be totally open to the malls. The two sides of the High Road are linked by a bridge at first floor level, which in itself will provide shopping and catering. Considerable car parking is provided, there being approximately 1670 parking spaces in multi-storey car parks above the shops. These car parks link with the present road system but provision has been made to link them to a new elevated road system which the GLC propose to construct on the north and east sides of the centre. Basements under parts of the site provide plantrooms and storage facilities.

The Centre displaced a number of small traders and some housing. Those small traders who wished to be relocated have now been re-housed in a market which has been created within the Centre. 200 dwelling units are being built above the shopping, together with a small amount of office accommodation. The housing is being built by the Metropolitan Housing Trust on the roof to the shopping, this roof being landscaped and planted in order to create a pleasant environment for this new community. Servicing and deliveries to the shops will not take place from the High Road as service yards have been created to allow deliveries to the backs of units, and avoid any street parking.

The architects have set a high standard in the design and the quality of materials used in all the landlord's and public areas, and it is intended that this will be repeated by the tenants with their own shopfitting. The scale of the building is minimized so that it fits in with the scale of the surrounding buildings. The majority of the latter are built of brick and this material has been used almost exclusively as a cladding material.

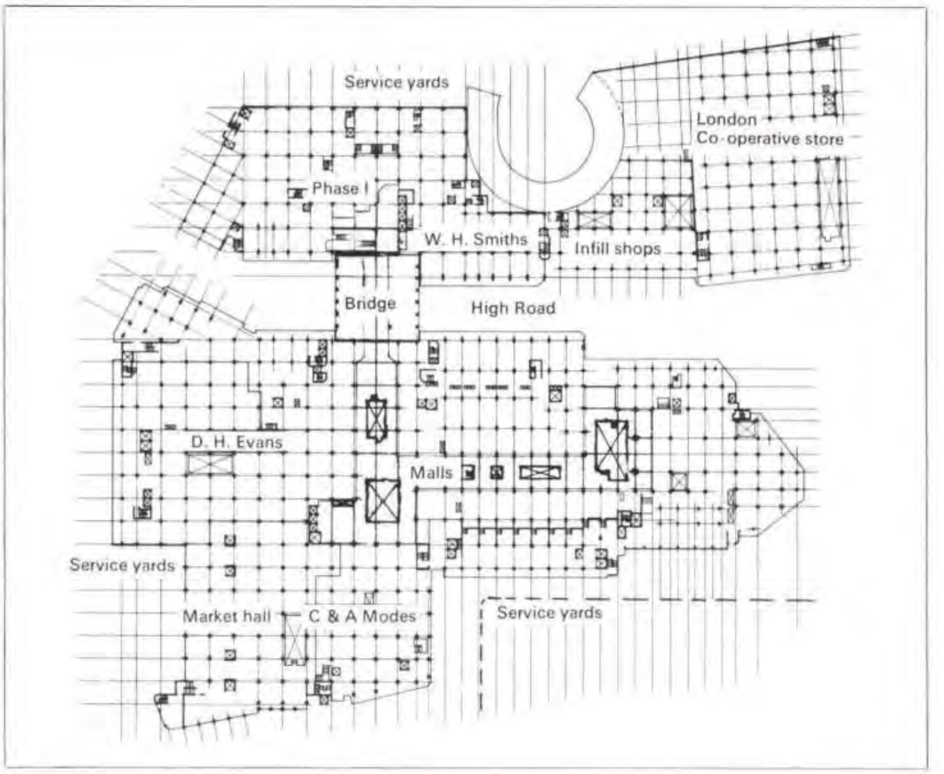
### Site and foundations

The site forms part of the Lee Valley catchment area and is subject to some flooding. There was a major drainage channel known as the Moselle Culvert passing across the site and this was diverted to pass along the northern boundary by the Lee Valley River Authority, now the Thames Water Authority. Site investigations were carried out by the Borough of Haringey and ourselves and these indicated there was a small amount of made ground before reaching London Clay.

It was clear from the beginning that foundations would be achieved by piling, but the decision whether to use groups of small diameter piles or single larger diameter piles under each column, was not so clear. Alternative schemes for each type were designed and costed, but finally, due to the alternating nature of the column loads as one moved across that part of the building which had long span multi-storey car park above, and to the housing being constructed of loadbearing brickwork, we chose groups of small diameter piles so as to minimize differential settlement. The Piccadilly Line passes under one corner of Phase 1 and it became necessary to pile within a metre of the tunnel and

**Fig. 3**
Wood Green: model of housing complex (*Photo:* courtesy of the architects)

**Fig. 4 (below)**
First floor plan of complex



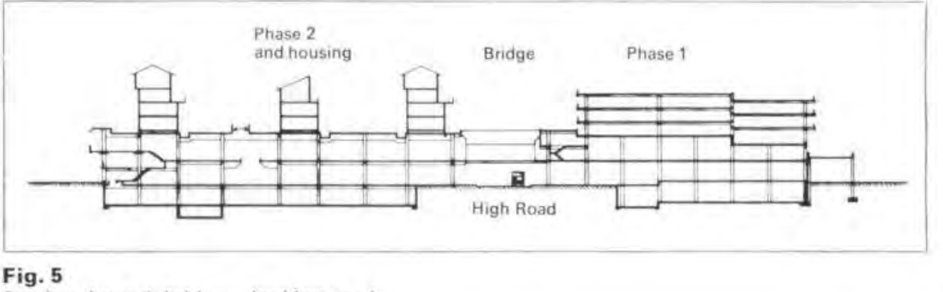




**Fig. 5**
Section through bridge—looking north

then cantilever certain pile caps over the Tube. Surveys in the Tube were carried out by the London Transport Executive before and during the works to ensure there was no adverse affect on the Tube tunnel.

**Basements**

Basements are provided for shop storage and plantrooms and in some instances are 6 m below surrounding street level. Where possible, conventional propped cantilever reinforced concrete retaining walls, 300 mm thick, were constructed in open cut, but considerable lengths required sheet piling to be used to ensure the stability of surrounding roads during construction. Generally the size of sheet pile chosen was sufficient to cantilever and avoid any form of propping but adjacent to Mayes Road it was necessary for it to be propped.

To avoid internal strutting, the contractors, John Laing, obtained permission from the local authority to place ground anchors in the clay beneath the adjoining road. The walls and basement slab were designed for water pressure and the slab design also took into account forces due to long-term heave in the over-consolidated London Clay. The basement is constructed of water-tight concrete, but waterbars have not been used. To achieve the standards of dryness required for storage, drained cavity walls and floors (Casco tiles) have been used extensively.

**Superstructure**

Alternative column modules were analyzed but finally the requirements of the car parking and of the housing defined the modules which would pass through or form the divisions between the shop units. Early on it was decided to have clear span parking bays to give greater flexibility of parking layout and easier manoeuvrability. This was achieved using a module of 7.4 m x 15.7m with additional columns being added in the mid-span of the long car park span at the shopping levels, thus giving a module of 7.4 x 7.85 m generally in shopping areas. Beneath some of the housing the module was reduced to 5.6 m in one of the directions so that direct support could be provided to the housing cross walls. In certain special areas such as the malls, beams with spans up to 22 m long became necessary to achieve large column-free spaces. All structure, with the exception of the bridge over the High Road, is of reinforced concrete, being either beam and solid slab or coffered slab. The long-span car park beams were of some concern because of the normal tendency for these to appear to sag and create oppressive spaces. To alleviate this it was decided to reduce the depth of these in the centre to 800 mm and slope down to the support. This reduction in depth of about 150 mm gives some arching effect which has helped considerably.

**Fig. 6**
General view of site showing sheet piles which are retained by ground anchors (*Photo:* John Laing & Son Ltd.)


**Fig. 7**
Entrance to Phase 1 shops (*Photo:* John Price Photography)

**Fig. 8**
Wood Green: Phase 1 shops with offices above (*Photo:* John Melling)

**Fig. 9**
Phase 1 shopping showing entrance to bridge in background (*Photo:* John Melling)

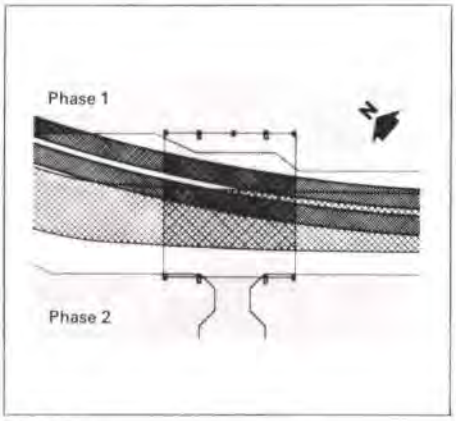



**Fig. 10a**
Plan showing High Road and Tube tunnels

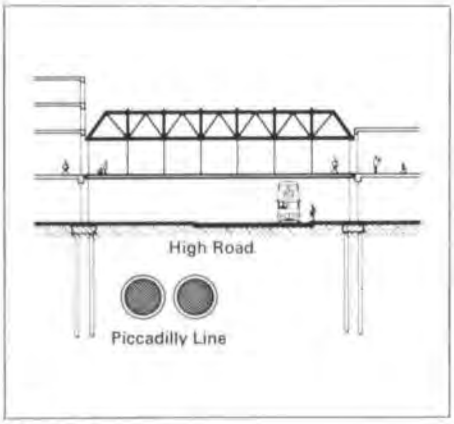



**Fig. 10b**
Section across High Road

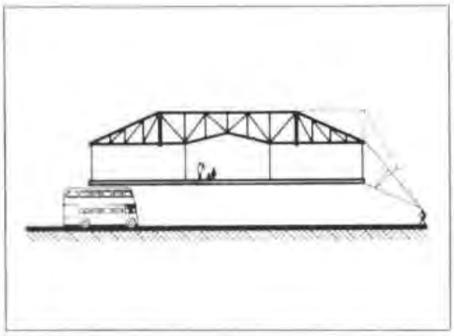


**Fig. 10c**
Section across High Road: main girders set in from edges, thus reducing apparent depth of bridge.

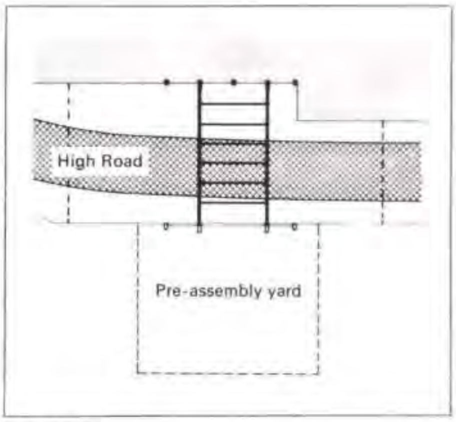



**Fig. 10d**
Erection of main girders with complete road closure

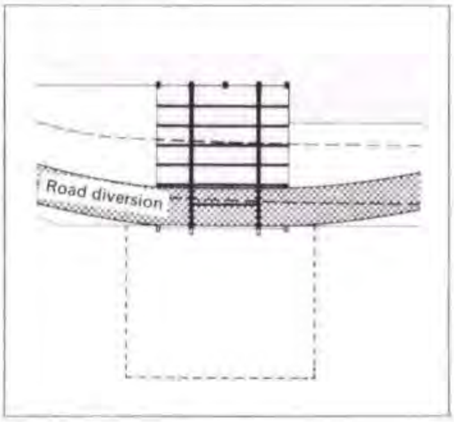



**Fig. 10e**
Road diversion during completion of east end

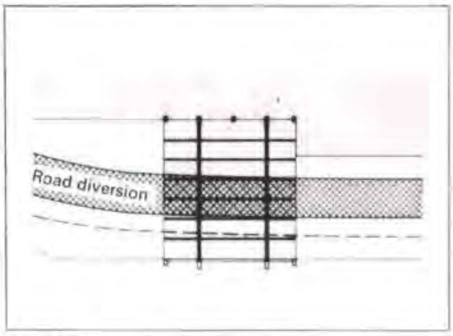



**Fig. 10f**
Road diversion during completion of west end

### Bridge

The bridge provides a pedestrian link between the malls on either side of the High Road at first floor level. It has a span of 30 m and is 30 m wide with both shops and a restaurant looking over the High Road. Its structural system had to be such that traffic could be kept moving during construction and that the slab level was the same as the mall first floor level, yet at the same time providing full Ministry of Transport headroom to the road beneath. The result of these two criteria meant that the overall construction depth, including finishes, at first floor slab level could be 500 mm only. It was therefore necessary to have the main load-carrying members at roof level, with hangers supporting the floor slab construction. Because of the erection difficulties, we investigated the possibility of precasting a long-span spine member and launching it across the road from one side. However, detailed investigations and architectural considerations made us choose structural steel. This of course needed fire protection, which was provided by a combination of dry lining insulation fixed to the steel members and sprayed-on insulation at the joints. The final structural solution comprised two main trussed girders spanning the High Road and being linked by transverse trusses that supported the hangers carrying the first floor. To allow for movement, the two main girders were supported on bearings. Andre Rubber bearings, giving sliding by means of PTFE coated plates and rotation through a rubber pot, were used. The sliding was restrained in certain directions, so as to provide lateral resistance to wind forces, etc. The loads at the bearings were 2840 kN with maximum anticipated horizontal movements of 40 mm.

The main girders, which were 30 m long and 3 m deep, were delivered in their constituent elements to an assembly yard adjacent to the west abutment where they were finally joined together before erection. Connections using friction grip bolts were used to simplify site operations. Erection of the main structural elements took place during two weekend road closures, the road being closed from late on Saturday evening until early Monday morning. All remaining work, including the construction of the concrete deck, cladding and finishes, was done with the road in operation. However it was possible to divert the road temporarily so that it only passed under one half of the bridge at one time leaving the other half free for building operations.

### Housing

The support for the housing is provided by the roof over the shopping area and is known as the 'housing deck'. Not only does it provide the roof to the shopping area, and as such has to satisfy the requirements for waterproofing, provide large clear spans beneath and allow for automatic smoke ventilation, etc., but it also is the foundation on which the housing is built. As such, it supports the load-bearing brick walls of the houses, provides a base for landscaping and access walkways and must provide all the services to and from the housing. In satisfying these requirements, it was also necessary to ensure that all maintenance of the housing and its systems could be carried out from above the deck, as it was important to ensure complete separation of housing and shopping. To achieve this, a system of large services ducts is built into the deck structure. These ducts carry all mains services with the exception of gas, which for safety reasons British Gas insisted should be in a separate duct. The housing is built to Department of the Environment yardstick standards with floor slabs of reinforced concrete and roofs of timber trussed rafters with tile cladding.

### Building services

A complex development such as a major shopping centre sets certain problems for the developer and services designer, not least of which is the fact that there are many tenants all with varying requirements. To minimize some of these problems and to achieve a high standard for the environmental conditions within the Centre, both in landlord and tenant areas, it was decided that primary services would be provided to all areas by the landlord. A further advantage of this decision was that it enabled one central energy centre to serve the whole complex, thus giving a situation that would be more efficient and energy-conserving than having many separate and smaller plants. It would also help longer-term maintenance and management, as it would be under the control of the landlord. Maintenance of the primary systems is also aided by ensuring that access to such systems is from the landlords' areas and not from the tenants'. The development had to be constructed in three main phases and this necessitated providing temporary plantrooms for the first phase until the main energy centre came 'on stream' in the second phase. Within these main phases there were in all 15 separate handovers which meant partial and progressive commissioning of some systems.

### Heating, ventilation and air-conditioning

The Centre can be broken down into a number of basic function types each of which has different requirements. There are large and small shop units, enclosed malls, a market hall, plantrooms and storage, offices and housing. The housing has a separate landlord and for management reasons is separate from the rest of the Centre, having its own district heating scheme with hot water provided by a boiler plant on the housing deck. The boilers have a total capacity of 1460 kW for the 200 housing units.

The energy centre for the remaining areas is situated in the basement and includes two gas-fired boilers (5560 kW total), three chillers (7000 kW total refrigeration) with all associated pumps, controls, transformers and

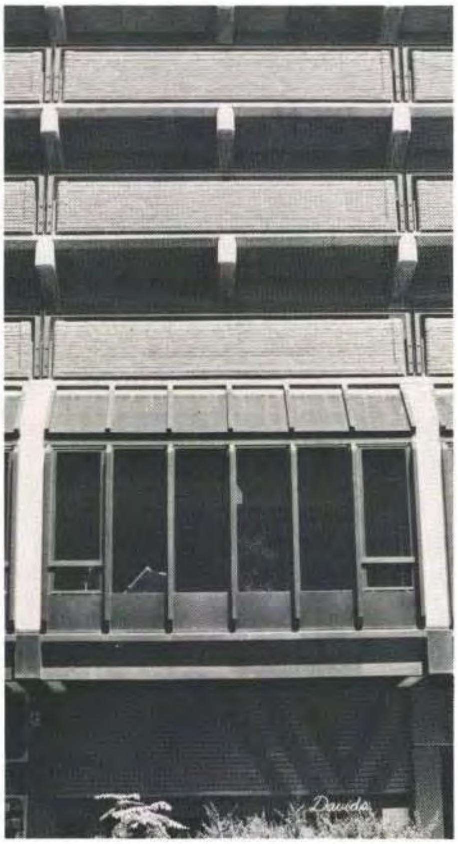


**Fig. 11**
Management Centre and car parking: cladding details
(*Photo:* John Melling)

**Fig. 12** right
Interior of Market Hall
(*Photo:* John Melling)

**Fig. 13**
The Market Hall showing stalls in background
(*Photo:* John Melling)


**Fig. 14** above
Phase 2 car park; garage on left of foreground; cooling tower on far right
(*Photo:* John Melling)

switchgear. The cooling tower is at roof level, but within the central drum of the exit spiral ramp. Air handling plantrooms would most naturally have been accommodated on the roof, but as all roof space was taken by either car parking or housing this was not feasible without an adverse effect on these other elements. The only exceptions to this are a small air handling plant on the roof of Phase 1 serving the offices and the air handling plant serving the D. H. Evans department store. The main air handling plants are located in the basement beneath the main mall in Phase 2, intake and extract of air being via very large builders work ducts that rise to roof level. There are over 30 fan units within the complex.

**Cooling requirements**

Initial analysis of the heat gains and losses for the shopping areas indicated that for the majority of the time, cooling would be required, so this, together with the requirement for good environmental conditions, meant that it was necessary to air-condition these. As it was also intended that all shops opening onto the malls should have a minimum of shop front and be open to the malls, it was important that landlords' and tenants' areas be treated in a similar manner. The malls and all the smaller shops are provided with conditioned air from the main basement plantroom. A conventional constant volume fresh air system supplies the malls and a variable air volume (VAV) system is used to supply the shops. Each tenant will obtain from the landlord a VAV control box, which he will install at the air intake to his unit. He then provides his own ductwork within his shop unit. In the case of the large shop units, only hot and chilled water are provided (104°C/82°C flow/return temperatures) and they are required to provide their own air-handling plantrooms.

The market hall has its own air-handling plant, which is provided with hot and chilled water from the energy centre.

The electricity supply is provided from Eastern Electricity Board (EEB) sub-stations. In the case of Phase 1 to the east of the High Street it is from two EEB sub-stations at 415/240V and for Phase 2 it is to two clients' substations at 11,000V. The housing is fed at 415/240V by EEB from a separate substation in the basement. The total estimated electrical load for the whole development is 4.5 MVA. There are landlord's main switchrooms adjacent to the points of supply. Generally armoured cabling has been provided to composite cubicle type switchboards utilizing miniature and moulded case circuit breakers with HRC fuses to afford the necessary short circuit protection.

**Communication and security**

In addition to the normal Post Office telephone systems one might expect on such a development, the Centre has its own communications systems, which are necessary both for security and management reasons. There is a management suite, which includes a central security control room where monitoring of the Centre's systems takes place. Linked back to the management suite is a public address system which has speaker outlets in all landlords' areas and all tenants are obliged to link into it via an ES (essential services) box provided within each unit. This allows for general announcements, music, etc. but, most importantly, provides the fire alarm system for the Centre. Each unit can over-ride all communications, except this alarm, over the PA system which is arranged with 'cascade priority'. Burglar alarms on external doors and closed circuit cameras in the malls, basement corridors and service yards, etc., provide the security staff with a means of monitoring problems that may occur. Burglar alarms are transmitted on Post Office telephone lines via a multiplex (time-sharing signal). There is an internal PAX telephone system which is used by the Centre management. Other alarm systems installed include heat and smoke detection, sprinkler operation, lift and plant maintenance.

The lighting installations have used fluorescent and discharge lamps where possible because of their longer life and cheaper maintenance, but many types of luminaires have been used depending on the effect required. Car parks have MBFU prismatic industrial fittings whilst offices are fitted with prismatic hot cathode fluorescent luminaires. The malls and foyers use hot cathode fluorescents generally of the direct low brightness pattern together with MBFU downlighters. Emergency lighting is provided throughout and in many cases is incorporated with the general lighting luminaires. Lighting in public areas and service yards is controlled centrally via contactors from group switches in the central security room.

**Fire**

Fire precautions and safety measures are of prime importance in a shopping complex, which will have very large numbers of people within it. Minimizing the size and rate of spread of fire was a main consideration and, to achieve this, the Centre is fully equipped with sprinklers everywhere. There are breakglass fire alarms and hosereels throughout. Control of smoke was also considered in conjunction with the Fire Research Station, the DoE and the Fire Officers, particularly in the malls where it could have an extremely adverse effect on people escaping. Downstand beams between each unit fronting onto the malls and continuing into the latter create smoke reservoirs and minimize smoke travelling along the length of the malls and tend to direct it to the smoke vents which are situated in the roof directly above them. The smoke vents are above the openings which occur in the first floor malls.

**Fig. 15**
Phase 2 Market Hall entrance with car park exit ramp above.
(*Photo:* John Melling)

**Conclusion**

Phase 1 and LCS were completed in 1976 and some shops, including the LCS, have been trading since then. The whole of the development to the east of the High Road is now open with all the shops let.

The Market in Phase 2 was officially opened in February 1979 and it is expected that D. H. Evans and C & A Modes together with a large number of the remaining shopping units and all public areas, will be open by March 1980.

**Credits**

*Client:*
Electricity Supply Nominees Ltd.
*Architects:*
Sheppard Robson and Partners
*Chartered surveyors:*
Richard Ellis
*Quantity surveyor:*
Gardiner & Theobald
*Main contractors:*
Phase I and LCS, H. Fairweather & Son Ltd.
Phase 2 and Housing, John Laing & Son Ltd.

# Al Fateh University Tripoli, Libya, Phase 1

**Architects: James Cubitt, Fello Atkinson and Partners**

Colin Wade

### Introduction

The last full description of the university project was given in the December 1974 issue of *The Arup Journal* when I attempted to briefly describe the history of its evolvement with a summary of phases which were being designed and constructed at that time, with emphasis on Phases 1 and 2 which were structurally well under way on site. Since then, these and other phases have been completed but, for space reasons, only Phase 1 will be dealt with here.

### Phase 1 Evolvement

Before the architects, James Cubitt, Fello Atkinson and Partners, became involved in the university, a few buildings of varying styles were already in existence and formed the basis for the eventual campus expansion. These existing buildings were not presumably planned for university status as, in 1964, the architects were asked to design some buildings for a college of advanced technology as an extension to part of the existing group. The first project with Arup involvement began in 1968 and was for a teachers' training college at the north end of the site nearest the Tripoli – Homs main road and the main campus entry point. During the design the project was renamed the Faculty of Education and, in addition, the Faculty of Agriculture, as well as the Dining Halls, were introduced to form Phase 1. A much later addition during the construction stage was the High Voltage Laboratory which began life under Phase 3 but was brought forward and given to the Phase 1 contractor as a variation order.

The project became the University of Libya, Tripoli and the architects prepared a master plan for the whole campus. Only much later was the name 'Al Fateh' adopted.

### Services

As Ove Arup and Partners had not begun Building Engineering at the outset of the initial project and had been asked to provide the services design, we sub-let this work to Kenneth Stead and Partners. However, after their involvement on many buildings, Ove Arup and Partners have taken over the remaining design and supervision of all phases. For this article I shall concentrate on the structural aspects of the project.

### Faculty of Education

This faculty comprises 13 inter-related blocks of one and two storeys with some basement areas, the blocks being grouped as far as possible to create formal landscaped courtyards with covered walkways linking them together. The functions are what would normally constitute a college, namely classrooms, lecture theatres, library, administration and in addition, a gymnasium.

### Structure

Our initial field trips had shown that reinforced concrete was the only viable method of construction as steelwork sections were imported, costly and generally difficult to obtain in the correct rollings and were not easy to erect satisfactorily. Prestressed concrete was also little used, again due to the lack of proper equipment and expertise of local contractors.

Most of the buildings are of framed construction with extra stiffening being given by in situ walls. Some floors are of flat slab construction with flares on the columns. Stability in these cases is given by shear walls.

Extensive use is made of sunbreakers in the form of horizontal concrete blades between columns. Our design and details were for a precast solution as there was much repetition, but the contractor surprisingly opted for casting them in situ and obtained a perfectly satisfactory result.

Much use has been made of reinforced, partly filled, hollow concrete block walls as infill and these were tied into the structure to prevent excessive damage under earthquake conditions. Our approach to the earthquake-resistant aspects will be discussed later.

Foundations are reinforced pad and strip footings tied in both directions by reinforced tie beams.

### Finishes

All finishes have been kept purposely simple using 'hard' materials, i.e. travertine floors, plastered and rendered walls and columns. The external surfaces have been painted white but, to give interest and faculty identity, some large areas of rendered infill walls have

**Fig. 1**
Faculty of Education: main lecture theatre and covered walkway (*Photo:* Svend Jensen)

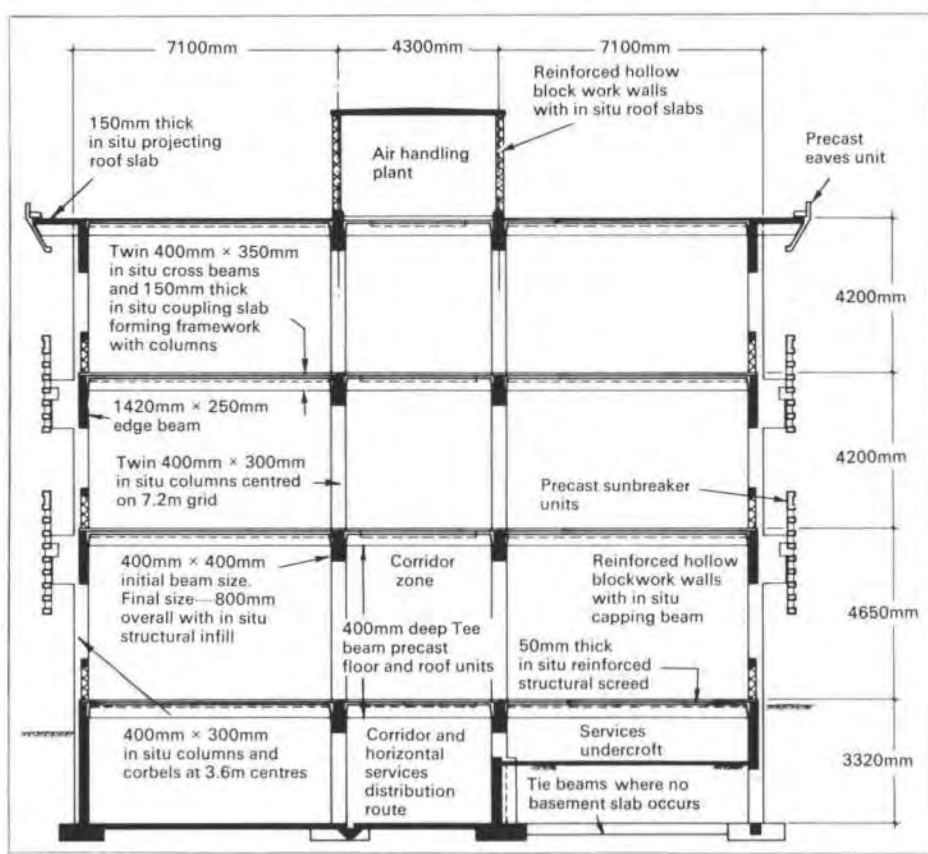
**Fig. 2**
Faculty of Education: classroom and gymnasium blocks with typical covered walkways (*Photo:* Svend Jensen)

**Fig. 3**
Dining Halls: typical dining area
(*Photo:* Colin Wade)

**Fig. 4** below
Dining Halls: entrance and foyer area
(*Photo:* Svend Jensen)

**Fig. 5**
Dining Halls: foyer area
(*Photo:* Svend Jensen)

**Fig. 6** below
Faculty of Agriculture: laboratory block D2, typical cross section




been slightly recessed with a pattern and painted in a contrasting colour (Fig. 1). Coupled with the grassed internal courtyard areas, the final result is very pleasant, particularly as the students are able to use these areas at most times of the year for meeting and studying, due to the temperate microclimate and the shading given by the covered walkways (Fig. 2).

### Dining Halls

It was obvious that the existing campus refectory would not cope with the projected student population so an early priority was for a separate dining hall with a fully equipped kitchen, roughly at the centre of the proposed master plan. The building was envisaged as being built as a squat 'T' shape in plan to be exactly mirrored in the future on the other side of the access road. At present only the first 'T' has been constructed. The building is single storey with a partly buried basement over the whole area containing all services, stores, etc.

The central kitchen and three large dining areas are all at ground floor level with cafeteria-type, self-service arrangements.

### Structure

This has been kept simple with a 9 m column grid using circular internal columns and long, slender, twin perimeter columns supporting twin roof beams in both directions carrying a solid slab (Fig. 3). The ground floor is of flat slab construction with no drops or flares but the basement columns are doubled up on a 4.5 m grid. Lateral stability is taken by frame action, with the basement storey providing a rigid box construction by virtue of the retaining walls. Foundations are pad and strip footings integral with the floor slab.

### Finishes

With the exception of dark coloured cork tiles on the soffit of the roof slab, these are all of a hard durable nature and the standard of workmanship has proved to be very high. The perimeter structure is entirely clad in travertine with a non-structural trellis-work of solid marble pieces between the columns and mullions to act as sunbreakers (Fig. 4). An overhang in the roof structure with a deep parapet, coupled with the trellis, gives a very cool feeling to the internal spaces. Another form of sunshading (also used on the other faculties) consists of infill panels of dark coloured screens formed as an open trelliswork from shaped fired clay 'bricks'. These are much used in the Mediterranean area and are most effective as a screen, allowing outside awareness and giving natural ventilation (Fig. 5).

### Faculty of Agriculture

This is the largest part of Phase 1 both in cost and size and basically comprises seven separate buildings. The largest are three laboratory blocks 136, 172 and 176 m long by 18 m wide. The two longest are three storeys high and the shorter is four storeys. All three have basements and partial undercrofts to give permanent access to the waste services from the laboratories (Fig. 6). To cope with thermal and earthquake effects the blocks have been broken down into bay

**Fig. 7**
Faculty of Agriculture:
covered walkway adjacent to recreation centre and bookshop
(*Photo:* James Cubitt, Fello Atkinson & Partners)

lengths of between 28 and 36 m with a joint width of 100 mm to avoid hammering of adjacent bays under earthquake conditions.

The other buildings comprise a two storey administration and library block, a single-storey recreation centre plus bookshop, a cluster of four lecture theatres and a single-storey stores and substation block. All are linked by covered walkways. (Fig. 7).

### Laboratory blocks – structure

Due to their size and the amount of repetition that was expected, it was obvious that some form of precasting should be adopted. The result was an in situ moment-resisting framework 'based' on a 3.6 m longitudinal planning grid with precast floor and roof elements.

To integrate the services and give adequate vertical distribution of pipework, twin columns were adopted internally on every second grid and these formed the riser positions. Single columns are placed on the perimeter at 3.6 m centres. Twin cross beams with an in situ coupling slab complete the framework. Thus a frame is formed at 7.2 m centres – the intermediate columns on the perimeter taking vertical load and giving longitudinal (but not lateral) frame action (Fig. 8).

The remainder of the floor and roof structure is formed from precast 'T' beam units spanning across the building onto a deep edge beam (to aid sunshading) and internal longitudinal beams. The support beams are designed to take initially the self-weight of the precast units and construction live loads. The floor units are concreted in place with a structural grade in situ infill and the composite beam section takes all permanent dead and live loads plus earthquake forces. A reinforced structural screed over the whole floor ensures that the floors act as stiff diaphragms and enhances the strength of the precast units for localized heavier loads.

A central area bay on each building houses the main staircase, lifts, toilets and toilet service risers and, as a consequence, is entirely of in situ construction. Other zones in the precast bays did unfortunately have to cater for extra lifts and stairs and this did disrupt the rhythm of the precast solution as in situ work had to be introduced. Also one block required even more extensive areas of in situ floors to cater for a teaching abattoir plus a dairy plant and its associated equipment.

### Precast work

The floor and roof units are single rib, 'T'-shaped components with only two spans of 3.9 and 6.5 m. All units are of identical depth, the only variation being in width of flange and main reinforcement. All services holes occur through the flanges and are standardized. The flange is also turned down at the end of each unit to act as a stiffening diaphragm and automatically acted as a side shutter to the in situ infill which completed the support beam section. Shutters were both steel and timber and although the finish is generally very good, very little is seen of the ribbed soffit effect in the completed building due to a suspended ceiling.

Other precast elements are large sunbreaker units which hang from in situ brackets on the perimeter columns (Fig. 9), and shaped eaves units which are supported by the roof slab (Fig. 10).

The sunbreaker units comprise a series of horizontal ribs spanning between vertical ribs which, with projecting reinforcement, were cast onto the column brackets with a system of bolts and shims to aid levelling and alignment (Fig. 11). As the units were not to be separated visually by any projecting mullions, it was important to obtain correct alignment, as can be seen from Fig. 12.

The eaves units were cast with an in situ, white, hammered, porcelain mosaic facing which was laid face down in the shutter. After some experimenting to obtain the most acceptable architectural finish and to achieve the best casting method, the mosaic was initially covered with a thin layer of concrete (25–30 mm) to hold it down; the final thickness was then poured and vibrated when the initial layer had partly set. Extra projecting reinforcement was provided to ensure the two layers were bonded together. The alignment of the units was important and projecting bolts were cast in the roof slab to connect with corresponding nibs provided on the rear of the unit. A continuous in situ stitch was then cast after alignment.

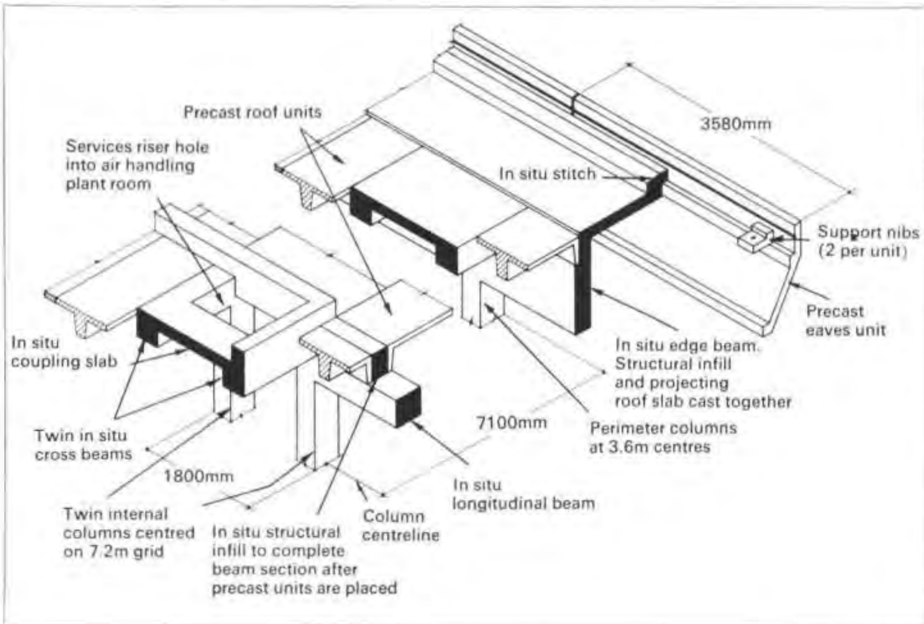
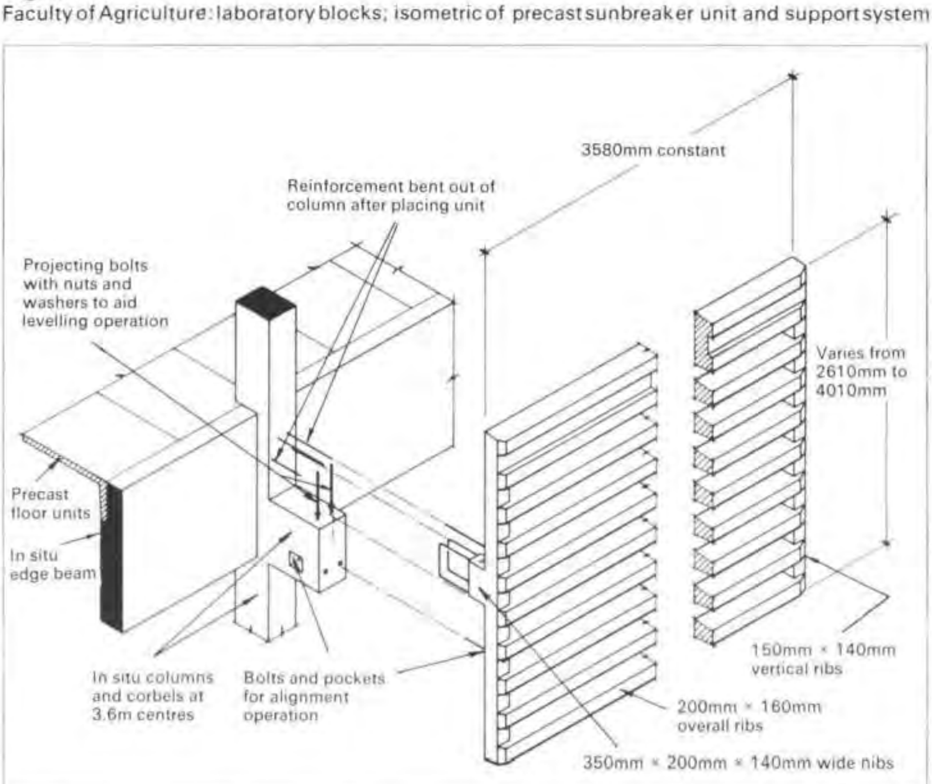



**Fig. 8**
Faculty of Agriculture: laboratory blocks; isometric at roof level showing main structural framework elements

**Fig. 9**
Faculty of Agriculture: laboratory blocks; isometric of precast sunbreaker unit and support system



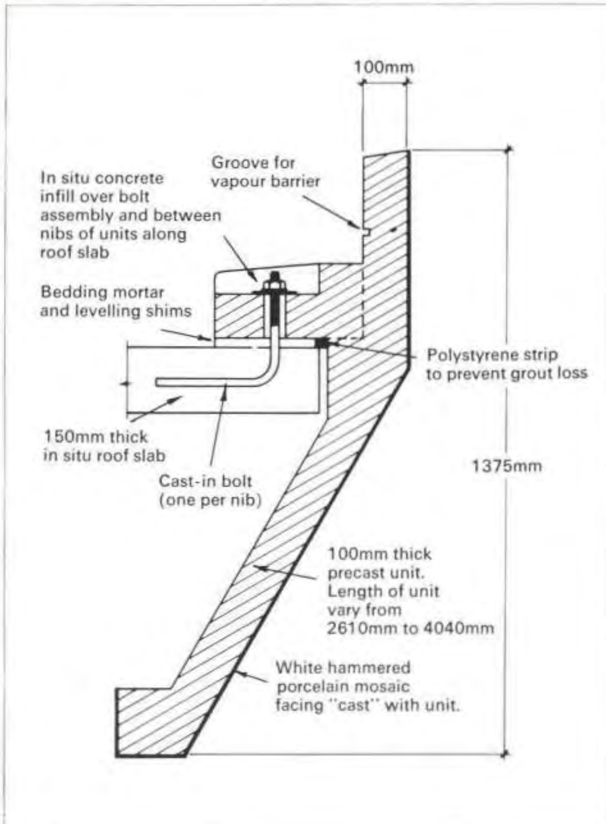



**Fig. 10**
Faculty of Agriculture: laboratory blocks; section through perimeter of roof showing precast eaves unit and fixing detail

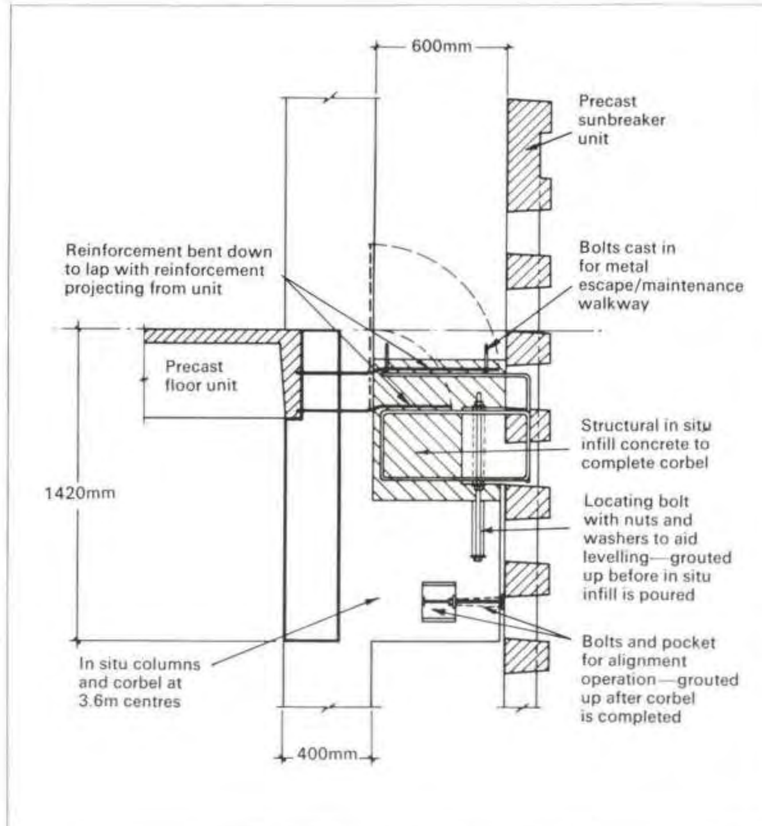



**Fig. 11**
Faculty of Agriculture: laboratory blocks; perimeter section showing sunbreaker support system

### Administration building

This is a two-storey block with a part basement, built on an arc of a circle in plan. The structure was of in situ framed construction with sunshading on the north façade being achieved with a series of arches as part of the longitudinal structural frame, set in front of the main façade wall (Fig. 13).

The most challenging part of this building was the requirement of a circular dome at roof level as a feature over the main conference room. This was constructed in situ and in itself was not a problem. The supports, however, were. The dome was required to be supported off a slab with an elliptical plan shape and assymmetrical column supports.

**Fig. 12**
Faculty of Agriculture: laboratory block D3 (*Photo:* Martin Jenkins)

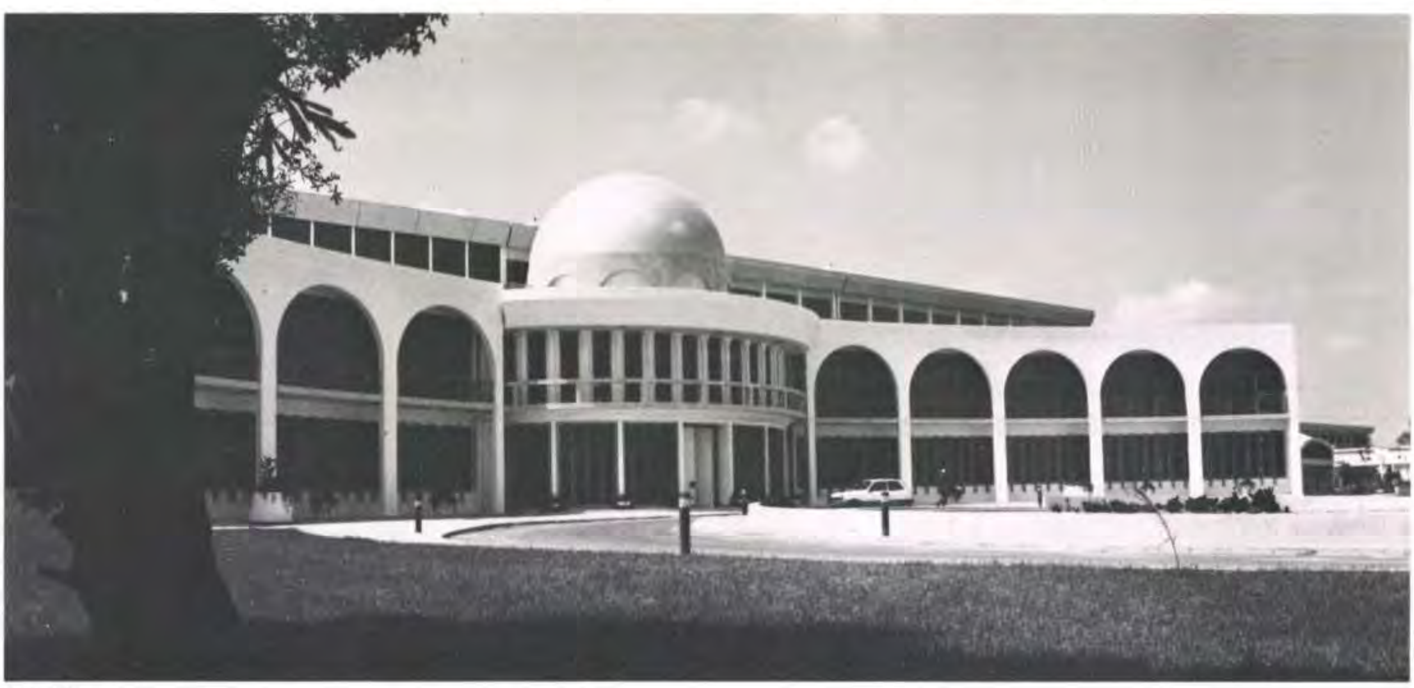


**Fig. 13**
Faculty of Agriculture: administration building (*Photo:* Martin Jenkins)

Although 'one off' and non-standard it was felt better to use a deep coffered slab. The edge ring beam thus formed is a continuous stiffened line support for the springing of the dome. Despite the complications in analysis and geometry the end result did not prove too difficult to detail or construct but it is disappointing that the combined visual impact of the dome and coffered slab is lost due to the introduction of a fibrous plaster second dome set inside the structural dome plus a flat false ceiling under the coffers.

### Recreation centre and bookshop

This is a very small part of the faculty and is somewhat overshadowed by the adjacent laboratory blocks but again, structurally, was an interesting problem. The recreation centre is a single-storey building and is basically a coffee bar with sitting area and comprises three connected domed shell roofs covering an area of 24 by 8 m. Edge beams at springing level take tie and frame action (Fig. 14).

The internal tie beams which span across the space at high level were required by the architect to give a neat horizontal stop for future demountable room dividers rather than let them meet the curve of the roof. Structurally of course they were very useful but perhaps less pure than one would prefer for a shell roof solution. The bookshop is a two-storey building with a single but smaller shell roof. Finish to all the shells is white glass mosaic on top and acoustic plaster to the soffits (Fig. 15).

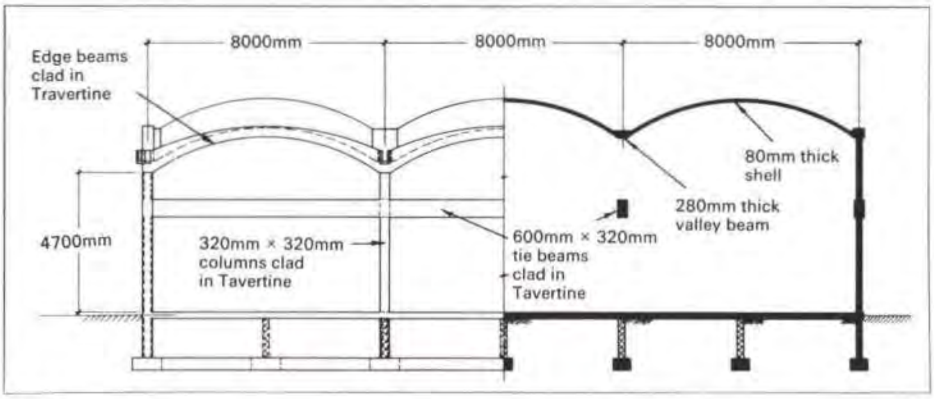



**Fig. 14**
Faculty of Agriculture: recreation centre; longitudinal elevation/section

**Fig. 15** right
Faculty of Agriculture: recreation centre and bookshop with laboratory blocks beyond (*Photo:* James Cubitt, Fello Atkinson & Partners)

**Fig. 16**
Faculty of Agriculture: rear wall of lecture theatre D4A (*Photo:* James Cubitt, Fello Atkinson & Partners)

### Lecture theatres

These are a cluster of four buildings with varying seating capacities arranged in a cloverleaf pattern with a coffered roof slab over the open concourse which separates them. All the theatres are reinforced concrete boxes with no internal columns supporting their roofs. The structure of all the roofs has been kept similar with an in situ transverse ribbed slab spanning onto two sets of twin downstand beams spanning longitudinally. The twin beams connect with a wide vertical air shaft formed behind the dais and the ventilation ductwork is taken from the shaft, between the twin beams and discharges downwards over the seating.

The raked auditorium floors are supported by dwarf walls or columns with the two larger theatres containing air handling and other plant in the spaces formed under the raking floors. Externally, the white tiled end walls have had coloured tiles set in to a pattern based on Arabic calligraphy to give interest and a different identity to the other faculties (Fig. 16). Natural light is provided through the side walls from vertical slit windows with in situ vertical and horizontal blades acting as sunbreakers.

### External works and foundations

Covered walkways in the form of simple reinforced concrete portal frames supporting a roof slab connect the buildings. Below are walkthrough services distribution ducts in reinforced concrete which run between the basements of the buildings. The duct system is joined to the main site services distribution duct, previously described in *Newsletter 100*. It is worth mentioning that the original design of the first three phases of the university was based on each faculty having its own independent energy source. It was only after the project was under construction that it was decided to build a central plant with an underground site distribution duct system. As a result the plant spaces allocated became partly redundant and in particular the two plant buildings set aside for the Faculty of Agriculture were re-allocated as a substation and storage area, the cooling towers and boiler flues being deleted.

Foundations for all buildings are pad and strip footings connected in both directions by tie beams. Where basements occur, the footings are integral and the floor slab acts as the tie member.

### Finishes

As for the first two projects, the finishes have been kept as simple as possible. Travertine has been used for much flooring and as cladding to the vertical structure in some entrance areas. The sunbreaker units to the laboratory blocks have been left as struck from the steel moulds and painted white. Very little structure has been left exposed. Where beams and columns are visible as framing on the elevations, they have been rendered and painted.

All blockwork infill walls are rendered and painted except for the substation and stores building where the panels between the portal frames have been built using textured blocks made by the contractor and left unpainted.

The fired clay sunshading trellis-work panels mentioned for the dining halls have also been used most effectively to screen the staircases on the gable ends of the laboratory blocks.

The dome on top of the administration building has been clad in gold mosaic.

### High voltage laboratory

For a newly developing university this project was a rather adventurous step for the client to take as the function of the building is to teach and test very sophisticated items of large electrical apparatus.

The building is basically one large test hall (Fig. 17) with a folded plate roof. On one side of the hall is a three-storey gallery comprising offices, lecture and ancillary rooms plus an observation/control room; plant is situated on

**Fig. 17**
High Voltage Laboratory: east elevation
(*Photo:* Svend Jensen)

the top floor. Smaller single-storey test rooms project from the main hall area at each end.

To carry out some experiments and tests, no outside interference must be allowed and the structure and all metal fittings and finishes must form a 'Faraday Cage' – this is achieved by welding all the reinforcement together and ensuring that it, and all metal components, are earthed.

**Structure**

The structure is virtually a reinforced concrete box with the walls supporting the folded plate roof stiffened by buttress columns. The 80 mm thick folded plate roof covers two unequal spans of 19 and 6.4 m. A 3 m cantilever at each end expresses the form of the roof from below and with a heavy parapet the resulting cantilever bending moment helps reduce the larger span moment. Foundations are pad footings under the buttress columns connected across the building with tie beams. Strip footings between the main pads carry the reinforced concrete walls. To handle the large items of equipment a 5 tonne capacity travelling overhead crane runs the whole length of the main hall supported by continuous in situ corbels from the walls (Fig. 18).

**Finishes**

Externally, the reinforced concrete walls of the main hall, which are well finished, have been painted in a buff colour to contrast with the basic reinforced concrete framework which has been left as struck. At ground level a deep, splayed plinth has been formed with travertine slabs around the perimeter. The smaller test rooms are clad in white porcelain hammered mosaic which is glued to the reinforced concrete walls.

**Fig. 18**
High Voltage Laboratory: main test hall showing test equipment and overhead crane (*Photo:* Colin Wade)

**Earthquake-resistant design**

Tripoli is in a low activity seismic zone but there are no local codes or regulations.

After the initial decision to design for a moderate earthquake risk was taken, we obtained as much information as possible on Northern Libya which included data on earthquake events from the Institution of Geological Sciences, Edinburgh, geological and tectonic maps showing fault lines, intensities, etc., from which we were able to build up our assessment of the degree of risk and intensity factors for Tripoli. We also had advice from Professor Ambraseys of Imperial College, London, to confirm our general approach to the area.

A static analysis was chosen since none of the buildings are tall or highly complex analytically and for the design approach we used the Californian (SEAOC) Code as we considered it to be the most comprehensive earthquake code. The United States Building Code was also used for evaluating the degree of earthquake risk which was considered as part of the generalized formula for calculating the base shear. This is the 'Z' factor and for the USA is obtained via their intensity zoning maps. Our own research showed that the range of intensities for Northern Libya lay between III and VIII and in the Tripoli area lay nearer VII on the Modified Mercalli Scale.

Having organized the design approach we next tackled the practical aspects of detailing for in situ concrete elements, bearing in mind all the constraints required by earthquake regulations which were then available. We felt that no published document adequately covered all the commonest building elements except for basic items such as beams, columns, and walls, and even these were treated in a simplistic and perhaps idealistic way. We evolved details for all elements occurring on the project and, as well as those mentioned above, we included staircases, parapets, foundations, foundation tie beams and retaining walls. The details were produced on A1 drawings for use by all the designers and reinforcement detailers to obtain as much consistency as possible. It is worth noting here that much of the work done in compiling these details was later incorporated, with amendments and additions to cater for higher intensity earthquakes, into the Arup earthquake manual produced by David Dowrick which has since been published.

As well as the reinforcement details we also produced a 'sister' manual which included the basic earthquake design formulae and general data for the concrete and blockwork elements in order to obtain a consistent approach for all the subsequent phases which began whilst Phase 1 was being progressed.

**Reinforced blockwork**

Externally much use has been made of hollow blockwork as infill and it has also been used to divide the internal spaces.

We made a conscious decision as part of the earthquake risk discussion to try and avoid large panels of masonry collapsing under earthquake conditions and not only causing loss of life but blocking means of escape. We have therefore reinforced, both vertically and horizontally, all perimeter and gable end conditions, all walls flanking or surrounding staircases and earthquake joints, as well as many other special infill cases.

As for the reinforcement details, we produced standard conditions to be applied throughout all phases. Panels are generally connected to the horizontal structure with starter bars and to the vertical structure by dovetail anchors projecting from cast-in slots. To save weight and for economy, most panels are vertically reinforced and filled with concrete in every fourth cavity and horizontally with ladder type bars every second course.

**Fig. 19**
High Voltage Laboratory and Faculty of Agriculture: view from top of central plant chimney (*Photo:* Colin Wade)

**Conclusion**

Despite our early fears of the possible outcome of the projects in this (and other) phases, the finished buildings have been produced to an extremely high standard of workmanship by a contractor working much of the time under difficult circumstances.

**Credits**

*Client:*
Al Fateh University, Tripoli

*Architects:*
James Cubitt, Fello Atkinson and Partners

*Quantity surveyor:*
W. J. F. Tillyard and Partners

*Services sub-consultants (to Ove Arup & Partners):*
Kenneth Stead and Partners

*Subsequent services design and site supervision:*
Ove Arup and Partners

*Main contractor:*
Osman Ahmed Osman and Company

*Mechanical services sub-contractor:*
Ikdam

*Electrical services sub-contractor:*
Balfour Kilpatrick International

# The British Library: pile test

**Architects:**
**Colin St. John Wilson and Partners**

Peter Evans
Nick O'Riordan

## Introduction

The new building for the British Library, which is to be built in London on the site of the old Somers Town Goods Depot on the north side of Euston Road adjacent to St. Pancras Station, has already been described in general terms in an earlier issue of *The Arup Journal*(1).

This article describes the site work carried out during the pile test programme and a detailed account of the findings will form part of a presentation of the overall foundation design for the project to be published in the future.

In the areas of the deepest basements, to the north and south of the site, the foundations will be single bored piles (Fig. 1). The deepest basements will require excavation to −5 m OD, about 24 m below ground level and 4 m into the Woolwich and Reading Beds. Altogether there will be over 300 piles of which 120 will be installed in the first phase of construction and pile loads will vary up to 15 MN. After the diaphragm walls have been constructed around the site boundaries, the piles will be installed and will be cast up to the level of the lowest basement. Steel columns will then be erected within the empty bores and will provide support to the floor slabs, as basement construction proceeds progressively downwards by mining.

As the lowest basement is below the level of the London Clay, the choice lay between founding on underreamed piles in the Woolwich and Reading Beds or on straight shafted piles in the Thanet Sands. During the construction of both the Northern and Victoria Line tunnels, considerable difficulty was reported with water-bearing sand lenses in the Woolwich and Reading Clay and their presence was confirmed during a conventional site investigation carried out in 1975/76. It was therefore considered that underreamed piles might not be feasible and that the best option was straight shafted piles founded in the Thanet Sands at a level of −22 m OD.

The loads will be carried by a combination of skin friction and end-bearing. As a consequence of the building construction sequence, the piles will in practice be progressively loaded by the columns at the same time as the surrounding soil is being unloaded by the excavation. Consequently, the behaviour of the piles will depend not only upon the stiffness of the founding material, but also very largely on the skin friction mobilized around the perimeter of the shaft. The latter component is important, particularly in the provision of tension reinforcement in the piles. Since the displacement of the piles under load is very sensitive to the construction procedure, it was considered essential that the piles be formed 'in the dry' without the use of drilling mud so that the open shafts could be inspected prior to concreting.

In order to verify the foundation design, and to check construction procedures, a comprehensive pre-contract pile test programme was undertaken between December 1978 and April 1979. This comprised three separate stages:

(1) Trial bores

(2) Test pile installation

(3) Load testing.

It was decided to test two piles, one 1 m diameter and sleeved to measure end-bearing, and one 1.5 m diameter to simulate a contract pile and to measure principally skin friction.

## Trial bores

Work commenced at the south of the site with the drilling of two 1.5 m diameter trial bores, Nos. 1 and 3, into the Thanet Sands to a depth of 41 m (Fig. 2). This material was dry, very lightly cemented, and had a tendency to slump into the shaft; attempts to clean out this material by hand or machine were not successful. It was therefore not considered possible to form satisfactory contract piles without the use of drilling mud to support the sides.

The Woolwich and Reading Beds were found

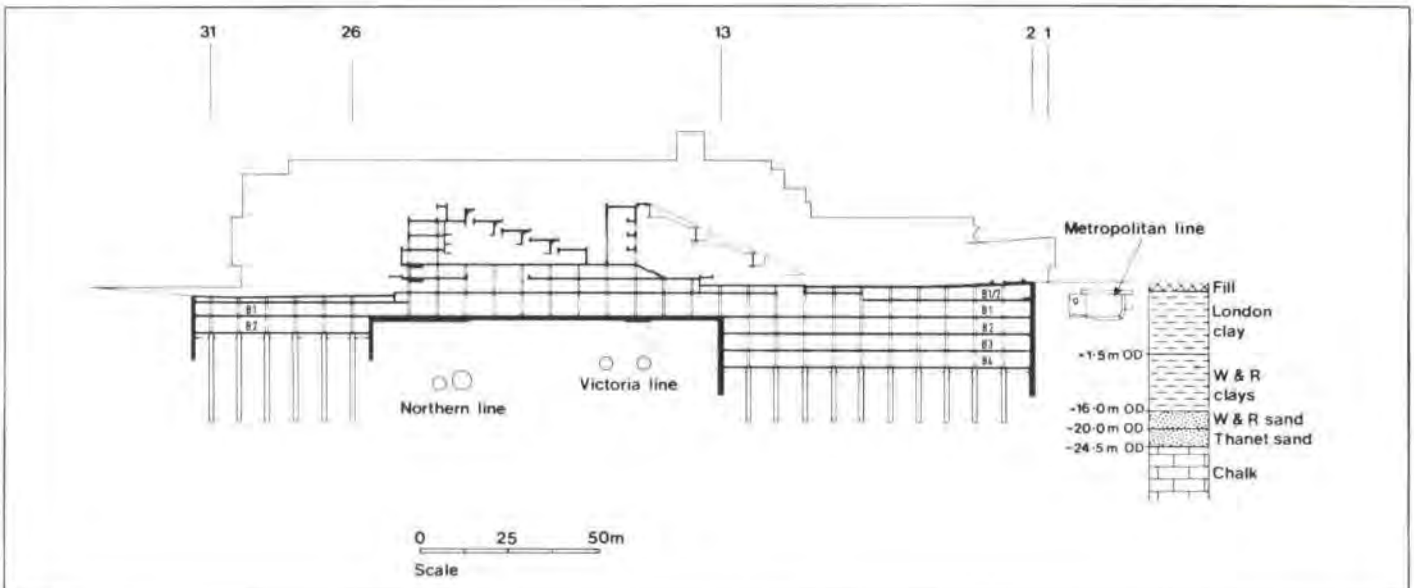



**Fig. 1**
North south section

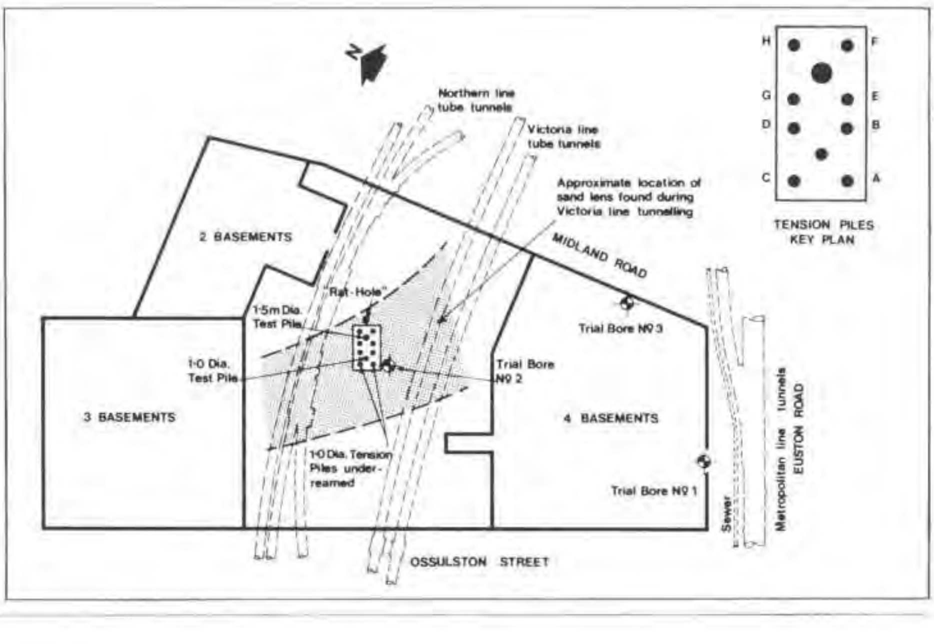



**Fig. 2**
Location of trial bores and test piles

to be clay at the top, becoming more sandy below about −16 m OD, and the shafts could be easily cleaned out in this material. The shafts were then backfilled in stages with a sand and cement mix to enable underreams to be formed at −16 m OD just into the sandier layer and at −13 m OD in the clay layer. The operations carried out in trial bore No. 1 are shown in Fig. 3. Contrary to expectation these were successfully constructed but were difficult to form because the material was very hard. It was therefore decided that the contract piles in this area should be straight-shafted and founded in the Woolwich and Reading Sands at −18 m OD. However, as this material is both weaker and less stiff than the Thanet Sands in which it was originally intended to found, the end-bearing capacity will be reduced and the deflections will increase.

As part of the investigation of foundation systems over the LTE tunnels in the centre of the site, a 5.5 m diameter underream, trial bore No. 2, was also constructed in the London Clay at 3 m OD.

### Test pile installation

The pile test was carried out in the central area between the Northern and Victoria Line tunnels, where there would not be any future contract piles and where the sand lens in the Woolwich and Reading Clay was also expected in order that the most onerous construction conditions might be encountered. This area was covered by the heavy Victorian deck structure for the railway goods depot and this was demolished before work started to enable the piles to be installed from ground level. The sequence of operations was as follows:

#### *'Rat-hole'*

This is an empty bore which was drilled and cased to facilitate the vertical assembly of the instrumented reinforcement cages (Fig. 4). The cage sections were spliced together with CCL couplers since it would not have been possible to fabricate the complete 40 m length of cage for each test pile horizontally on the ground and then lift it to the vertical and install it in the pile without damaging the instrumentation. Neither would it have been possible to leave the pile shafts open for the several days required to assemble the cage and instrumentation in situ.

The opportunity was taken in the 'rat-hole' to drill on into the Thanet Sands and then to construct an underream in the Woolwich and Reading Sands. This stratum was found at a greater depth than in the trial bores and this fact was taken into account in determining the founding levels for the test piles.

After the contract piles have been installed, the empty bores, extending the full depth of the basement, will be left open for a considerable period of time before the steel columns are erected inside them. Liners will be necessary, and it is proposed to use corrugated *Armco* casing as this is considerably cheaper than traditional steel casing. The opportunity was therefore taken in the 'rat-hole' to check this alternative and a 19 m length of *Armco* casing was successfully installed. The 'rat-hole' will be left open in order to monitor the behaviour of the casing under horizontal ground pressure loading over a period of time.

#### *Tension piles*

Eight underreamed piles were installed to provide reaction for the two test piles. These tension piles were approximately 18.5 m deep with 1.05 m diameter shafts and 3 m underreams.

#### *1 m test pile*

The 1 m test pile (Fig. 5) was designed to measure end-bearing behaviour and consisted of a 1.05 m diameter, 20 mm thick steel casing with a 100 mm steel plate welded to the base and filled with concrete, reinforced with 12 Y 40 high yield steel bars. To eliminate skin friction the pile was sleeved with a 1.15 m diameter steel outer casing. The pile was founded at level −18 m OD to coincide with the proposed level of the contract piles and so that a failure could occur completely within the Woolwich and Reading Sands.

The pile was instrumented with three rod extensometers and one magnetic ring extensometer. Displacements at the top of the pile were measured in the usual way from reference beams by dial gauges on each of three reference plates located at the top of the pile.

The compression of the pile was measured by rod extensometers which consisted of ball-jointed rods, 2 m long, inside an oil-filled PVC tube down to the base of the pile. The displacement of the base of the pile, relative to the top, was measured by a dial gauge mounted at the top of the pile with its anvil on the topmost rod.

Vertical displacements at points at intervals up the pile were measured using a magnetic ring extensometer. Ring magnets were placed at 3 m or 6 m centres down a PVC access tube. These magnets were embedded in the concrete of the pile and their relative positions were detected by a chain of reed switches mounted on a steel tape connected to a micrometer measuring head, capable of a reading repeatable to ± 0.05 mm.

#### *1.5 m test pile*

The 1.5 m test pile (Fig. 6) was designed to measure both skin friction and end-bearing behaviour. The pile was sleeved for a depth equal to that of the basement to simulate the contract piles, and polystyrene was placed below the base so that the skin friction could be measured separately from the end-bearing component. The lower end-bearing capacity of the Woolwich and Reading Sands, compared with the Thanet Sands in which it was originally proposed to found, increases the importance of the skin friction component in the pile design and a founding level of −20 m OD was chosen for the 1.5 m test pile to mobilize as much skin friction in the Woolwich and Reading Beds as possible.

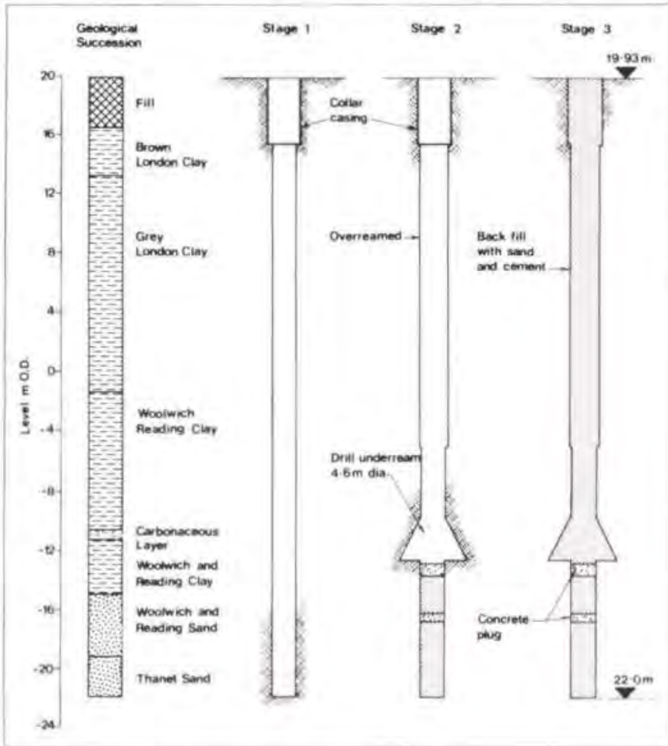



**Fig. 3**
Trial bore no. 1

**Fig. 4**
Cage for 1.5 m diameter test pile being lifted from the 'rat-hole' (*Photo:* Frank Gadd)

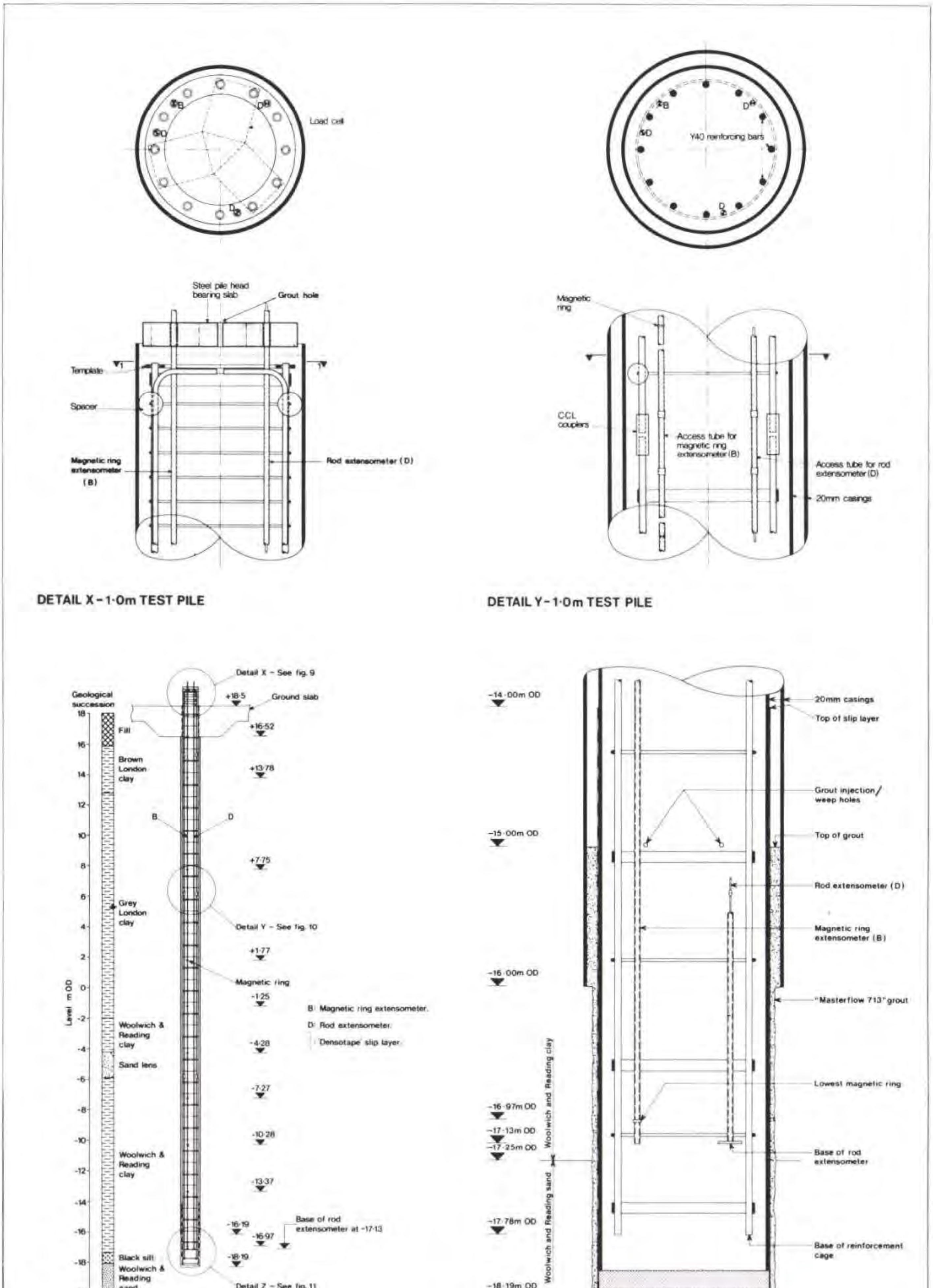



**Fig. 5**
1.0 m test pile

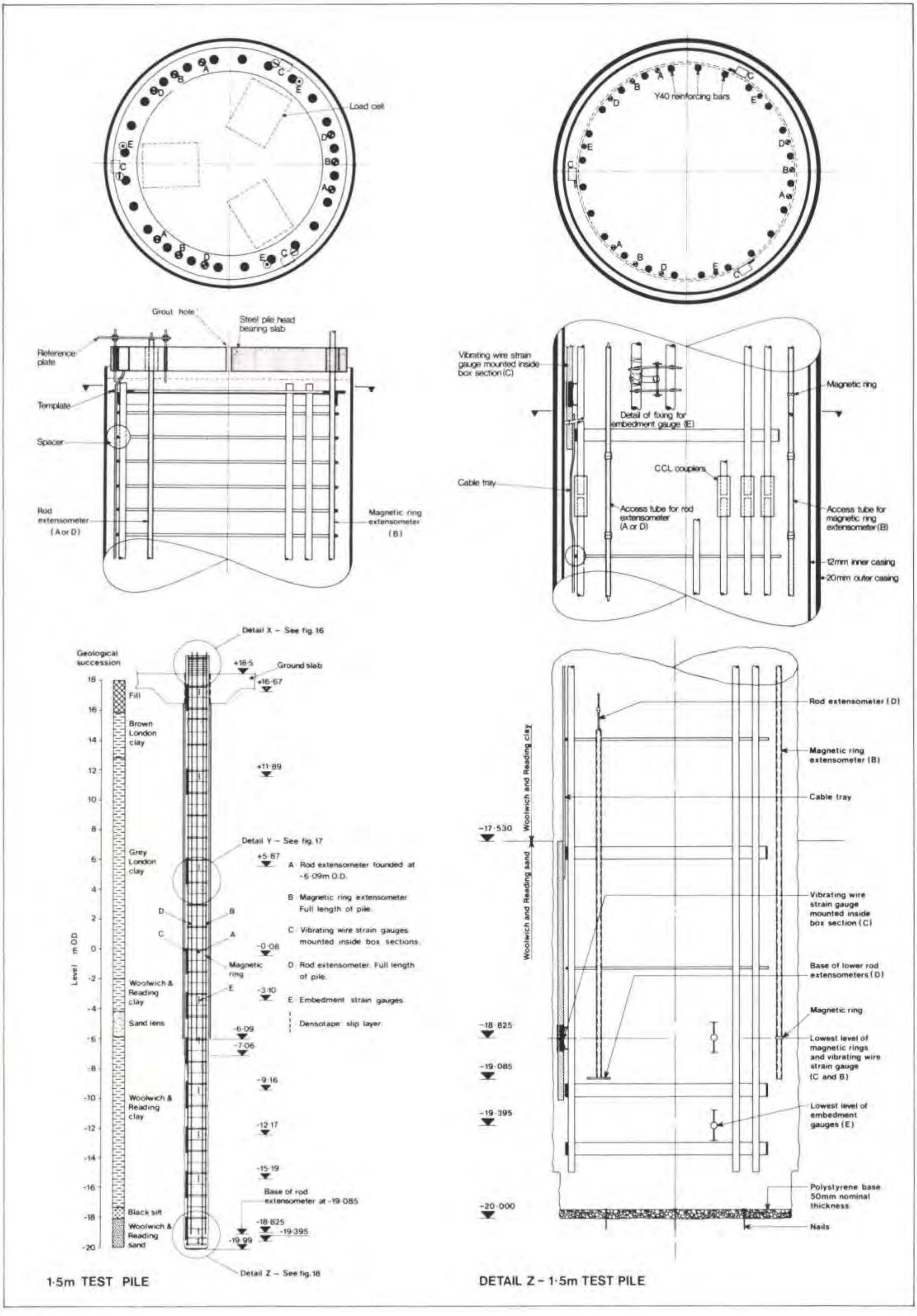



**Fig. 6**
1.5 m test pile

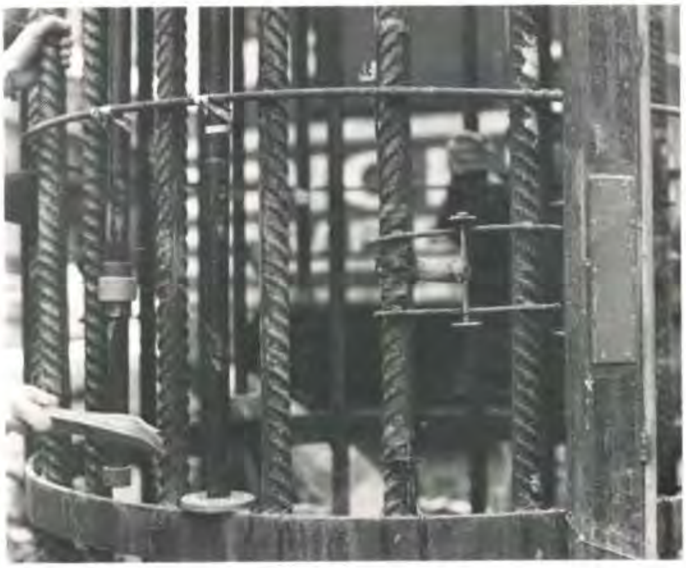


**Fig. 7**
Reinforcement cage showing, left to right, magnetic extensometer, rod extensometer, embedment strain gauge and vibrating wire strain gauge mounted inside box section (*Photo:* Frank Gadd)

**Fig. 9**
Reaction assembly (*Photo:* Frank Gadd)

The pile was instrumented with six rod extensometers, three magnetic ring extensometers and sets of vibrating wire strain gauges.

The displacements at the top of the pile were again measured in the usual way by means of reference beams and dial gauges.

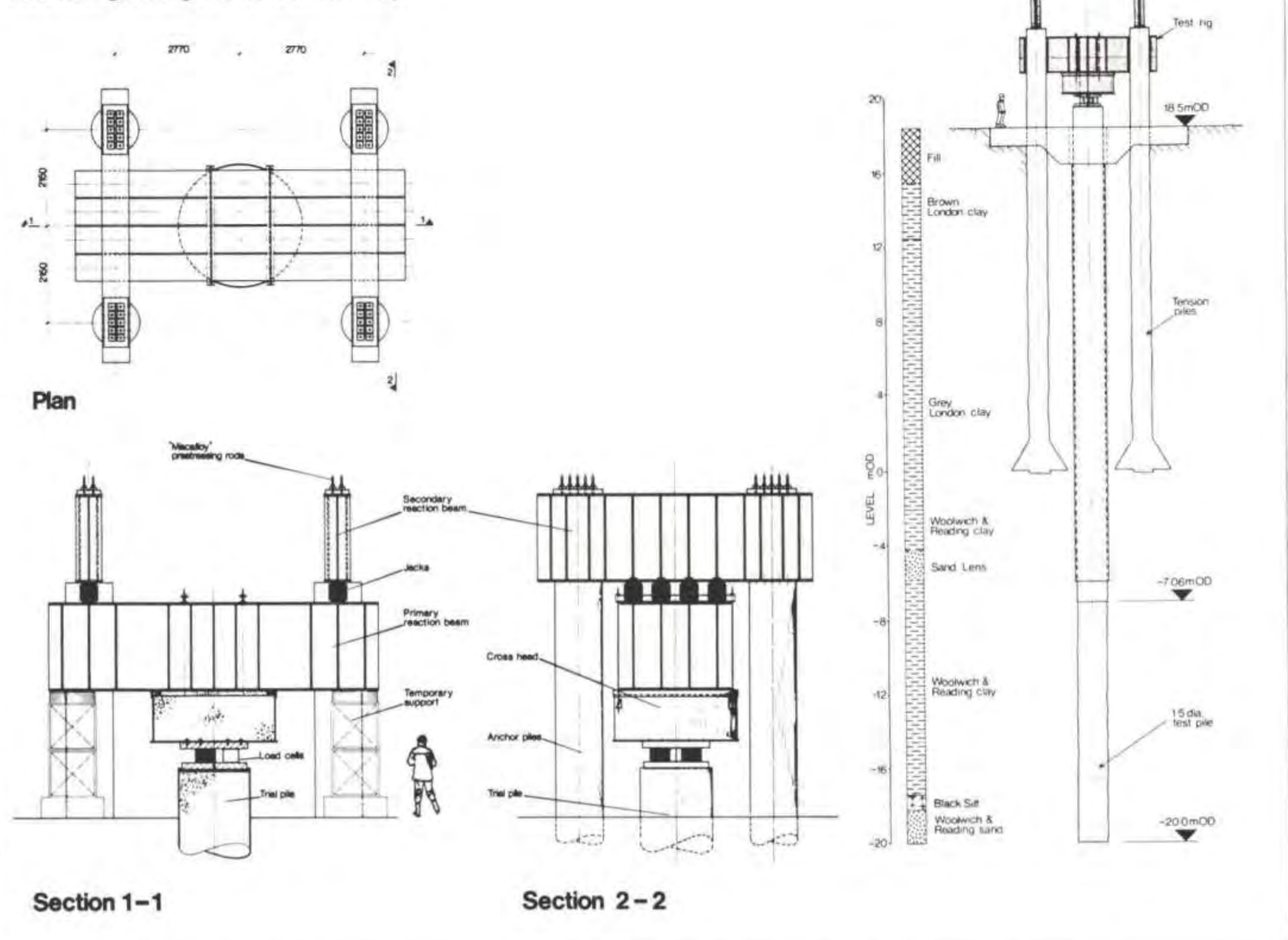
The compression of the complete length of the pile and the sleeved length were measured separately using rod extensometers with three terminated at the base of the pile and three at the bottom of the sleeved section.

The displacement and strain within the pile were measured using magnetic ring extensometers and strain gauges (Fig. 7). Surface-mounted vibrating wire strain gauges were located inside steel box sections fixed to the reinforcing hoops, and embedment-vibrating wire strain gauges were tied to the reinforcement. All 30 surface-mounted strain gauges worked throughout the test period and 19 of the 30 embedment strain gauges worked throughout with one of them mysteriously coming to life during the testing.

### Load testing
#### *Reaction assembly*

During the pre-tender period it was established that existing reaction assemblies did not have the capacity to provide the maximum test load of 22.5 MN. Alternative approaches for achieving this load were investigated, including augmenting the capacities of existing test rigs by using kentledge or by auxiliary systems of jacks, reacting against the existing structure. None of these alternatives, however,

**Fig. 8**
Load testing; test rig and reaction assembly



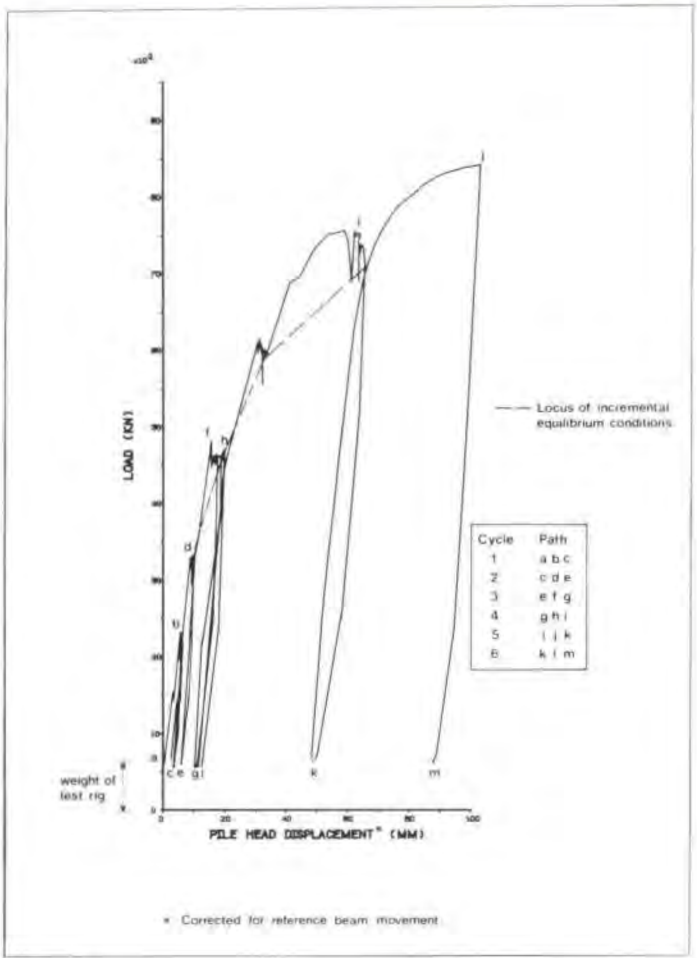



**Fig. 10**
1.0 m test pile:
load vs. head displacement

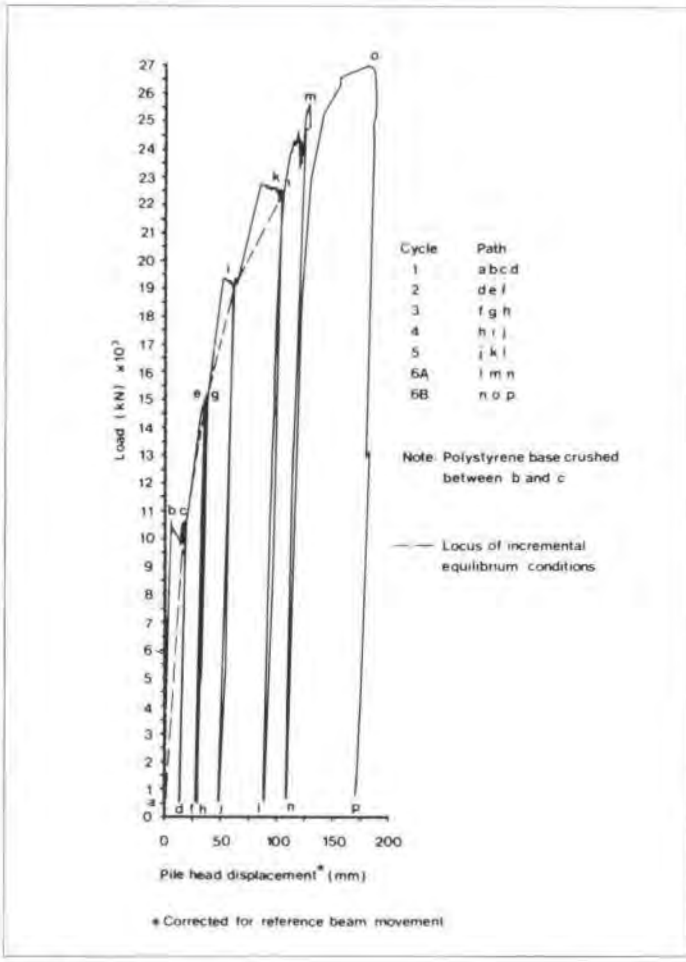



**Fig. 11**
1.5 m test pile:
load vs. head displacement

was considered satisfactory and a purpose-made reaction beam assembly was designed and fabricated during the tender period for the main pile test contract. All the major components of the reaction assembly were purchased or hired directly by the client.

The loads were transmitted from the tension piles to the test piles by four primary and two secondary steel reaction beams made up from heavily stiffened *Autofab* plate girders 2 m deep by 600 mm (Figs. 8 and 9).

Load was applied to each end of the primary beams by eight jacks reacting against the secondary beams which were anchored to the two pairs of tension piles, extended above ground level, by Macalloy bars which were stressed to prevent the reaction beams lifting when the load was applied.

The load from the primary beams was collected by the crosshead, which was a reinforced concrete-filled steel drum, and applied to the pile through three 10 MN capacity load cells. The load cells were placed between 150 mm thick steel plates in order to distribute the concentrated stresses.

The reaction beams were designed for a working load of 22.5 MN. The jacking system, Macalloy bars and load cells were designed to accommodate loads greater than this so as to avoid these components working at full capacity when the maximum load was applied. Advantage was taken of this provision in the 1.5 m diameter pile test and a maximum load of 27 MN was applied.

### *1 m pile test*

Five incremental load cycles were applied, with increasing loads in successive cycles (Fig. 10). Each increment of load was held constant until the rate of settlement dropped below 0.05 mm in half an hour at which point the pile was considered to have reached equilibrium.

In the final increment of the fifth cycle the load was allowed to drop from 7.5 MN to 7.2 MN in order to obtain equilibrium, a process which took over four hours. This indicated that another incremental loading cycle would not be possible as the pile was approaching failure. A Constant Rate of Penetration (CRP) test was therefore carried out instead in which the pile was loaded at a rate producing a displacement of the pile head of about 1.25 mm per minute.

### *1.5 m pile test*

Five incremental load cycles were also applied to the 1.5 m test pile based on a design load of 15 MN (Fig. 11). The final increment of the first load cycle was terminated at 10.4 MN since a relatively large displacement during that increment suggested that the skin friction forces had been fully mobilized and that the polystyrene base was being crushed and a CRP test was carried out as the last increment of the second load cycle from 10.4 MN to 14.8 MN to confirm this.

The fifth load cycle attained a load of 22.5 MN taking 16 hours to reach equilibrium and therefore a CRP test was carried out as the sixth cycle. The pile failed at 27 MN and the full extent of the jack travel, 190 mm, was reached.

## Conclusions

The pile test programme enabled the following conclusions to be drawn:

**(1)** The Thanet Sands are cohesionless and are not sufficiently stable to form satisfactory piles without the use of drilling mud.

**(2)** The Woolwich and Reading Clay and the Woolwich and Reading Sands were found to be dry and stable. The best construction option is considered to be straight shafted piles founded at −18 m OD, near the base of the Woolwich and Reading Sands.

**(3)** It was shown that satisfactory underreams could be formed in the Woolwich and Reading Beds to gain additional load capacity if required, but the construction was laborious and was at the limit of machine capabilities in the UK.

**(4)** The sand lens, from which there were strong seepages of ground water, can be sealed off by driving casings through it.

**(5)** The London Clay at this site exhibited discontinuities and seepages which caused blocks of clay to fall off the sides of the shafts. This material needs to be concreted or supported with a minimum of delay.

At the time of writing a detailed analysis of the test results is being carried out. The results and the way they are used will be reported at a later date.

## Credits

*Client:*
Department of the Environment

*Architect:*
Colin St. John Wilson and Partners

*Services engineer:*
Steensen, Varming, Mulcahy and Partners

*Quantity surveyor:*
Davis, Belfield and Everest

*Piling contractor:*
Lind Piling Ltd.

*Instrumentation:*
Soil Instruments Ltd.

*Reaction beams:*
Redpath Dorman Long Ltd.

## Reference

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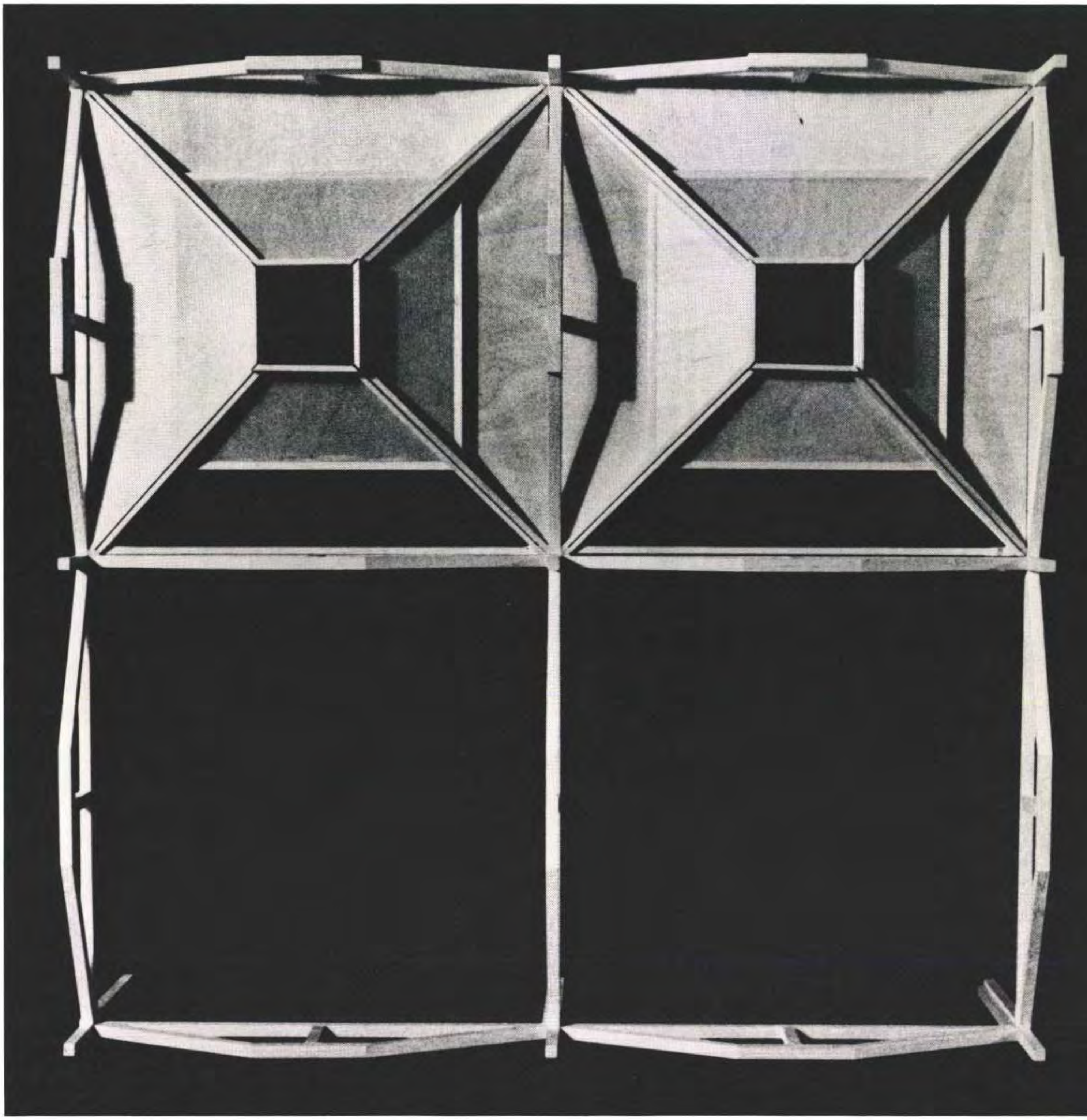

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