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Contents

Front cover: Hong Kong, 1857 (illustration by courtesy of Mary Evans Picture Library)

Carlsberg Brewery, Northampton

Neil Barbour

Introduction

The Carlsberg brewery in Northampton is now virtually complete after nine years of continuous development. As Stage I of this project has been described in detail in the March 1974 *Arup Journal*, this article is concerned mainly with the differing methods of project management used and deals only briefly with technical aspects of design.

Project history

In 1847 J. C. Jacobsen founded his lager brewery on a hill just outside Copenhagen, naming it Carlsberg after his son Carl and berg the Danish for mountain. The annual production of this brewery was equivalent to about four hours of brewing in the Northampton brewery but it did start the tradition of Danish lager. Up to this time, the Danes had brewed – and liked – English type ales, but this was to be no more and Carlsberg flourished. Exports to this country started in 1868 and just over a hundred years later Carlsberg decided to build a brewery in this country to meet demands.

The Northampton brewery site was chosen because of the availability of land adjacent to an old Watney Mann Brewery which was already scheduled for demolition. Planning permission for a new brewery to replace the old was easy to obtain and the transfer of trained personnel from the existing to the new brewery helped to ensure a smooth start.

The original brief was to construct one 100m. litre brewery within a period of just over two years on land reclaimed by diverting the river Nene. The design had to be such that the production capacity of the brewery could be doubled after demolition of the old brewery buildings.

Lager sales in this country have exceeded expectations during the last few years and Carlsberg had to increase production over the nominal capacity of 100m. litres almost from the day of the first brew. This increase has been achieved in the successive stages described below:

Stage I 1971-73 Job No. 3772	100m. litre production by five day batch brewing.
Stage II 1974-75 Job No. 5544	Seven day brew capacity by installing additional secondary fermenting tanks and external hard-standings for the storage of empties. 130m. litre capacity achieved.
Stage III 1976-77 Job No. 6113	250m. litre production created by installing a second brew line.
Stage IV 1978-79 Job No. 8428	Additional packaging and storage facilities provided by extending the main building.

Design organization

Ove Arup & Partners have been responsible since 1970 for the design of the structures and mechanical and electrical services. For Stage I we were appointed to provide quantity and cost control services for our own design work. For Stages II-IV, quantity surveying and cost control has been the responsibility of Ernest Howard & Son, a Northampton firm of quantity surveyors.

The design of the process plant was undertaken by Carlsberg's own design team, CPDT, but the co-ordination and programming of their design was part of our management responsibility. Knud Munk, working on a time basis, has been the architect throughout and has influenced the design of every aspect of the brewery.

Lay-out

When outline proposals were produced in 1971 for Stage I, a master plan was prepared which included the development of the area then occupied by the Watney Mann Brewery. At that time the building site was enclosed by the River Nene to the west and south and by the old brewery buildings to the east and north. The site was divided into three zones each running from south to north. The western zone between the brewery building and the river was reserved for storage tanks while the eastern zone was for traffic circulation and for the external storage of empty containers. The central zone was for the brewery building with the possibility of expanding northwards to house additional packaging and storage facilities. The brewhouse and energy centre at the south end of the building were designed with capacity for additional plant for a second brewline. This was the 1971 concept of development and although production demands have changed since then, the overall development has remained essentially unaltered.

Architecture

In the design of the brewery building the architect has tried to express the brewing process whilst preserving adequate flexibility for future plant alterations if required.

The building is 275 m long, 70 m wide and is contained within in situ concrete flank walls, with a profile that follows closely the space demands of the plant. The roof line falls from the 36 m high energy centre and brewhouse towards the fermenting cellar and again to the packaging and warehouse areas. It continues at low level over the new warehouse and rises again over the canning hall at the north end.

The basic materials used are concrete, steel and glass. Wherever possible applied wall finishes have been avoided and the concrete walls left as struck. The making good of concrete has never been permitted and this has proved to be correct architecturally as even large surface blemishes in the concrete are lost in the immensity of the façades.

Concrete was selected as the basic construction material only after the relative merits of concrete and structural steel had been investigated. Initially, steelwork seemed likely to result in a shorter construction programme, but was less suited to a closely integrated design and construction programme. In addition, uncertainty existed in 1971 over delivery periods for certain steel sections and prices were subject to fluctuation.

Structure

As the site consists of approximately 5 m of fill overlying blue clay the main part of the building is carried on driven in situ piles, the only exception being the bright beer basement where the 9 m depth allowed the use of spread footings in the blue clay.

The main structure of the building is of in situ reinforced concrete flank walls with a folded plate roof of in situ concrete over the energy centre and brewhouse and of precast, pretensioned concrete elements elsewhere in the Stage I building. The roof over the new warehouse, however, is of steel construction – a change dictated by cost and by a sequence of construction that gave priority to the completion of the canning hall. This imposed physical limitations on the warehouse site which precluded the use of precast roof units. The northern part of the building, which contains the canning hall and canteen consists of 'A' frames at 9.6 m centres supporting floor and roof units precast on site.

The brewhouse and energy centre equipment is supported on steel portal framed structures completely independent of the shell. The north and south façades of the building are totally glazed with angle frames 4.8 m long supported on structural steel mullions. These mullions span 25 m on the more dramatic south façade and are stepped back to give a profile to match that of the roof.

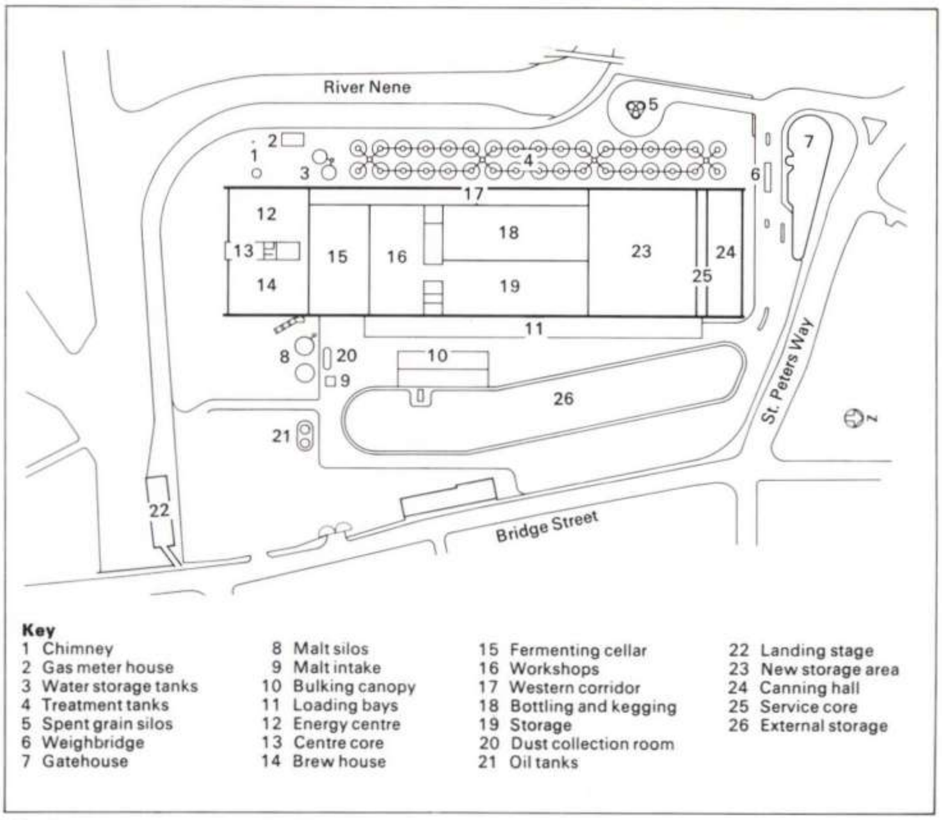


Fig. 1
Site plan

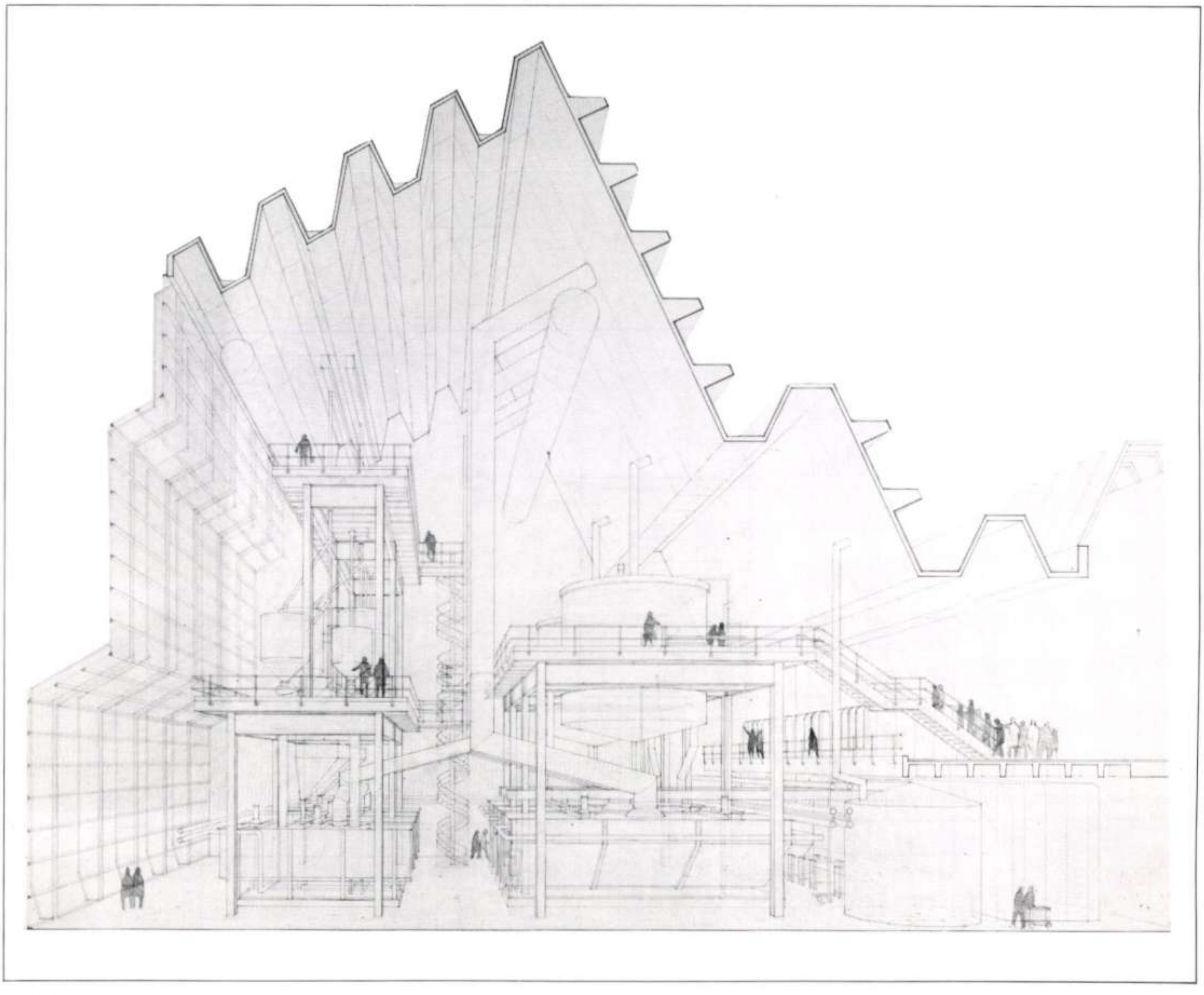


Fig. 2
Architects' drawing, showing interior, one wall removed

Mechanical services

The mechanical services provided are as follows:

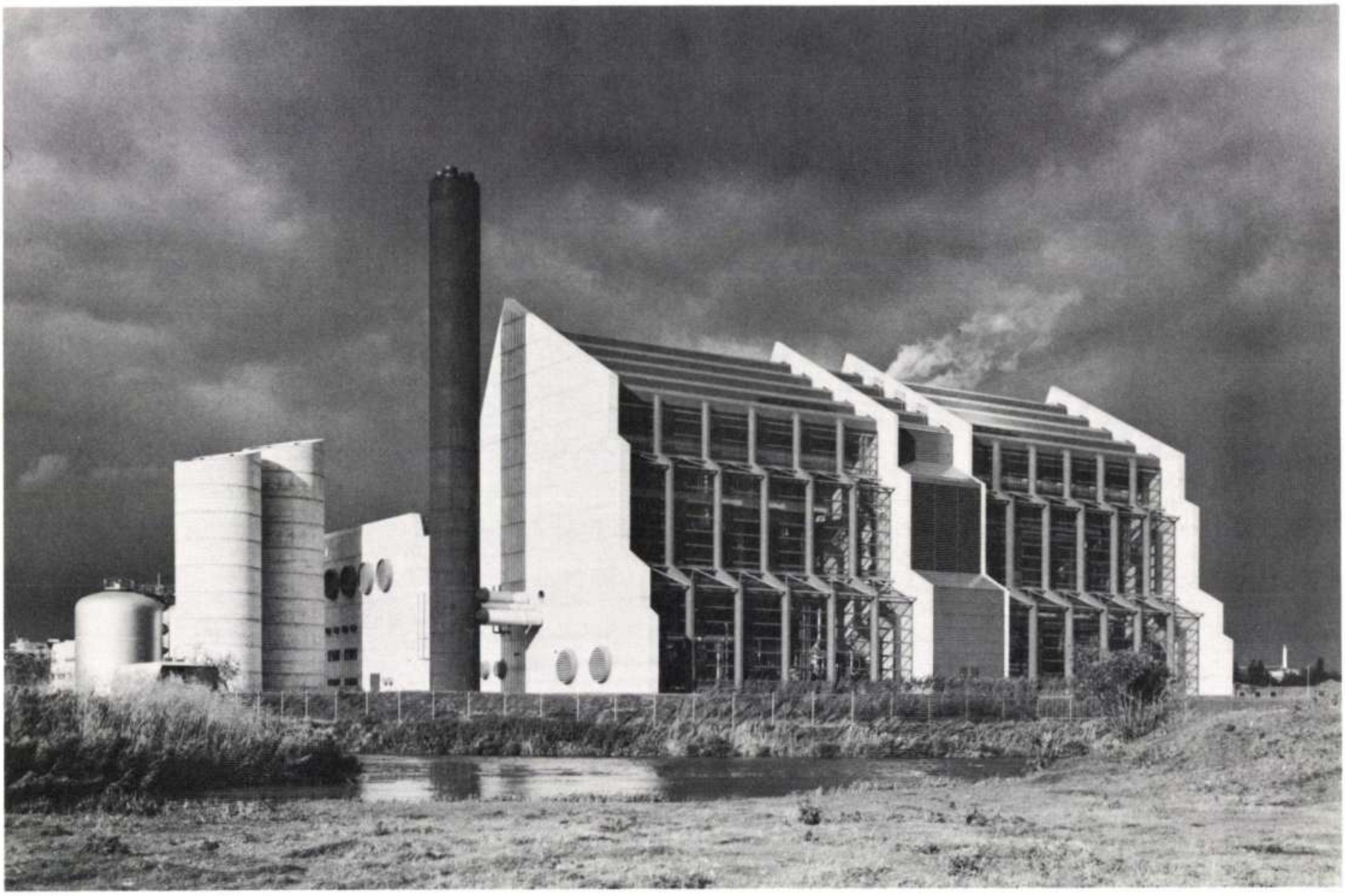
(1) Process cold water
(2) High pressure hot water
(3) Steam
(4) Refrigeration
(5) Equipment cooling water
(6) Compressed air
(7) CO_2
(8) Distilled water
(9) Drainage
(10) Drinking water
(11) Fire fighting
(12) Ventilation and air-conditioning
(13) Low pressure hot water

The process cold water is obtained now from two sources. Water for the brewing process is obtained from the Anglian Water Authority and that for cleaning comes from wells on the site. The chemical composition of the well water makes it unsuitable for the brewing of lager, although it had once been used for the brewing of local ales. The water is stored in two cylindrical concrete water tanks on the west side of the brewery.

The boiler hot water is provided at flow and return temperatures of 174°C and 149°C by four 9000 kw and one 2300 kw fire tube boilers. Originally, the only fuel used was natural gas but in 1975 the Gas Board decided that they could no longer guarantee Carlsberg an uninterrupted supply of natural gas. As a result of this, standby facilities had to be installed. Two oil storage tanks were erected immediately east of the silos and dual purpose burners installed on all five boilers. The Cor-ten chimney was heightened by 10 m to comply with environmental regulations and now has a 10 m band just below the top level which is visibly at an earlier stage of weathering.

The refrigeration system uses ammonia and glycol respectively as primary and secondary refrigerants. The system circulates glycol at —6°C through the brewery to all space and process cooling equipment with the exception of the fermenting tanks which are cooled by chilled water.

Fig. 3
The south façade of the brewery is totally glazed with stepped mullions 26 m high at 4.8 m centres. The steelwork is slate green in colour, as is the steel cladding to the centre core. This core provides lateral stability to the brewhouse and energy centre sections of the brewery and houses air handling and electrical equipment (Photo: Colin Westwood)



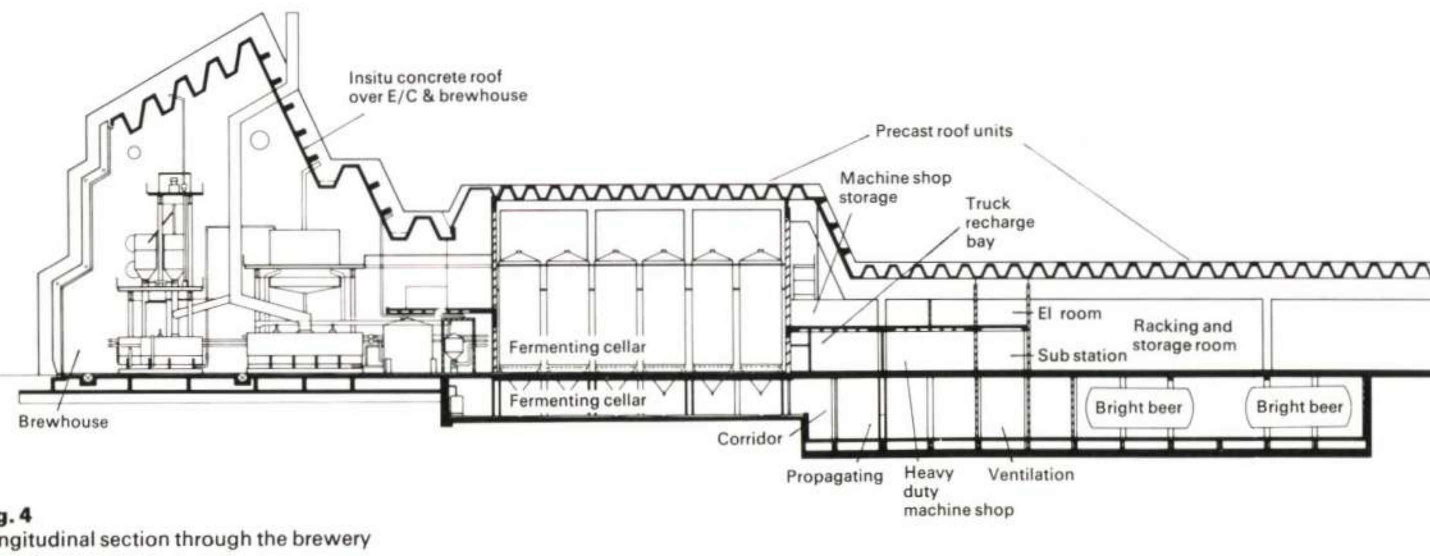


Fig. 4
Longitudinal section through the brewery

Electrical services

Electricity is supplied at 11,000 volts from the Northampton ring main by two feeders to the intake switchboard in the centre core between the energy centre and the brewhouse. Substation distribution within the brewery is by 11 kv ring main connecting five distribution substations. At these substations the voltage is transformed to 415/240 volts for power drives and all other services except for the 650 hp refrigeration compressor drive motors which are fed at 3300 volts from individual transformers.

Four main types of lighting have been used within the brewery. High bay MBF/U fittings have been used in the high ceiling areas of the energy centre, brewhouse and packaging areas. Fluorescent fittings are used in the Stage I warehouse, however, as prolonged exposure to the high ultra-violet content in certain light sources has a damaging effect on bottled beer. In the new warehouse high bay high pressure sodium fittings have been used for this reason and for economy. Elsewhere in the brewery the lighting is incandescent.

Process engineering

The Carlsberg Process Design Team (CPDT) is responsible for the design of all process equipment. Although the team has carried out basic scheme design in all cases, the specialist contractors listed below have been used to carry out detailed design and installation.

Brewhouse	Anton Steinecker Ltd.
Process controls & pipework	APV : Alfa-Laval
Tanks	Burnett & Rolfe : Rustfri Staalmontage
Bottling line	Barry Wehmiller
Kegging line	Burnett & Rolfe
Canning line	MetaMatic

This method of design, while unavoidable, has caused problems of design co-ordination, particularly with foreign-based contractors. These contractors have often been unwilling to commit themselves to a design programme and even less willing to make design changes to suit other consultants.

Project management

Ove Arup & Partners have acted as prime agents to Carlsberg since work started on the Northampton project in 1970. The method of project management has varied however from stage to stage.

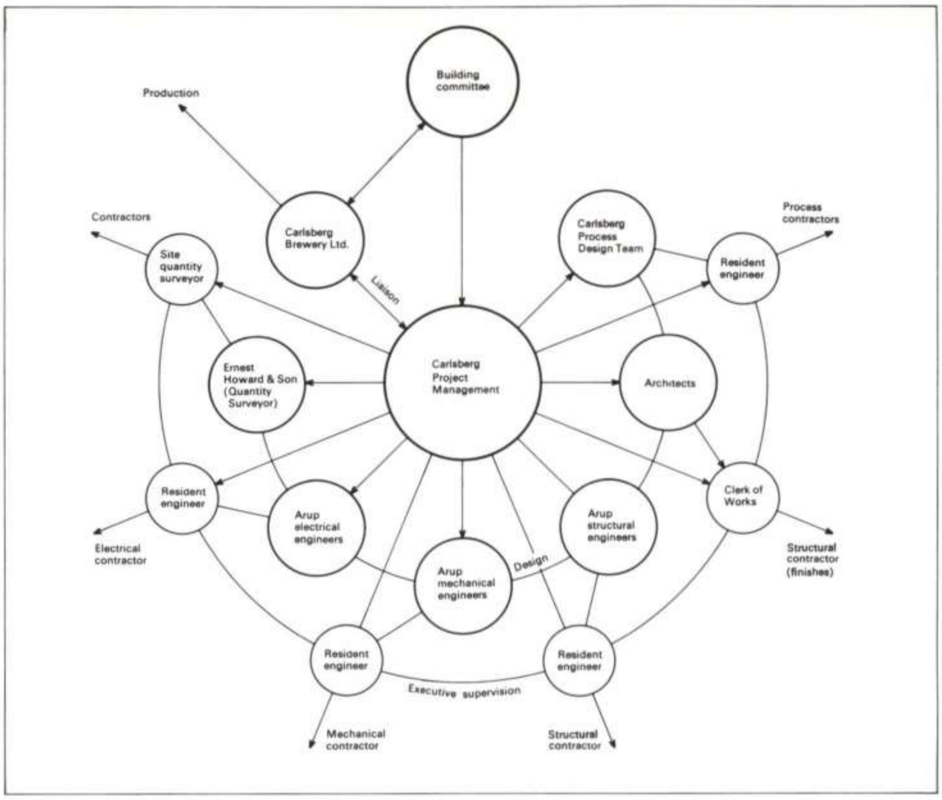


Fig. 5 Organization chart
Short circuits in communication are unavoidable but must be minimized to ensure project control. To do this, the Project Manager's office must be an efficient communications centre and equipped accordingly from Day One.

Stage I

Soon after being commissioned for the project, we decided that the first stage lent itself to a management contract partly because of the size and complexity of the project, but particularly because of the very tight programme required by the client. Nine possible contractors were selected and interviewed and a short list of four were asked to submit written proposals. After considering these proposals, George Wimpey M E & C were appointed firstly for advice only, paid on a time basis, and then for the management of contractors, this service being paid for as a lump sum plus expenses.

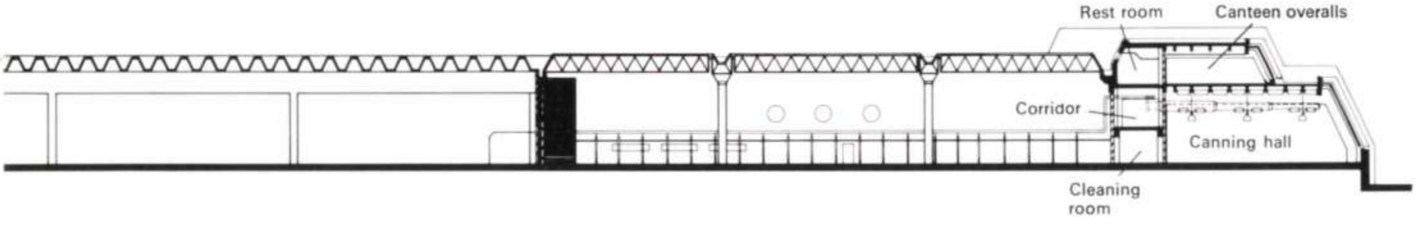
The management contractor was responsible to Ove Arup & Partners for the following :

(1) Contractual advice
(2) Site supervision
(3) Programming of the work
(4) Pre-ordering of plant and materials
(5) Provision of central site services
(6) Settlement of claims and final accounts.

The appointment of a management contractor enabled design and construction to proceed simultaneously and facilitated the advance purchase of plant and equipment on long delivery. During the scheme design period, a small team from Wimpey's worked alongside the designers in London and established the logic of construction and installation sequence. When foundation work was completed on site, this group moved to Northampton to form the nucleus of a much larger site team.

Ove Arup & Partners were responsible for the preparation of tender and contract documents and for the nomination of contractors. The contractual framework was then such that all Stage I contracts were drawn up between George Wimpey M E & C and the various nominated construction and supply contractors but without directly involving the client.

Basically all of these contracts were awarded either on the ICE Conditions of Contract or



those of the I Mech E Model Form A. with the contractors selected from not less than three competitive tenders. The management contractor was responsible for measuring the work in progress and agreeing interim valuations and final accounts, which were in all cases submitted to Arups for approval before presentation to the client for payment.

The labour force on site during Stage I reached a peak of 900 men in 1973. 20 main contractors were involved in building and service work and 51 for plant and equipment. The co-ordination of so many companies was not easy and George Wimpey M E & C needed a staff of about 100 to ensure smooth operations. The quantity of paper work generated on the project was astounding. This was partly because of the need to record a multitude of site meetings and partly because of the duplication of site instructions. Arups' instructions were issued to George Wimpey M E & C and then re-issued by the management contractor to the contractors. This was found necessary to keep the chain of command clear and unambiguous.

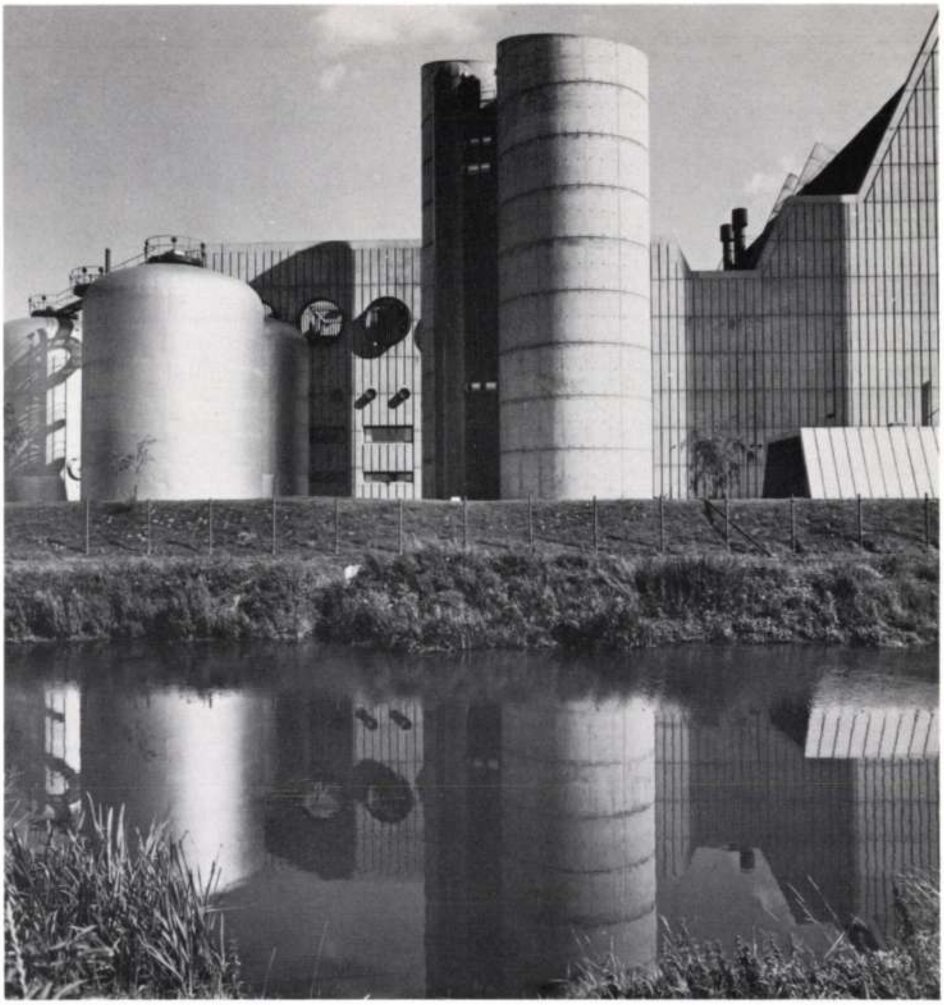


Fig. 6
The roofline of the brewery building follows the space demands of the plant, thereby economizing on energy use
(Photo : John Donat)

Fig. 7
The longitudinal façades are of in situ concrete with 2.6 × 0.6 m panels created by deep vertical and horizontal rebates. The 36 m high brewhouse wall acted as a freestanding cantilever prior to the construction of the in situ folded plate roof
(Photo : Colin Westwood)

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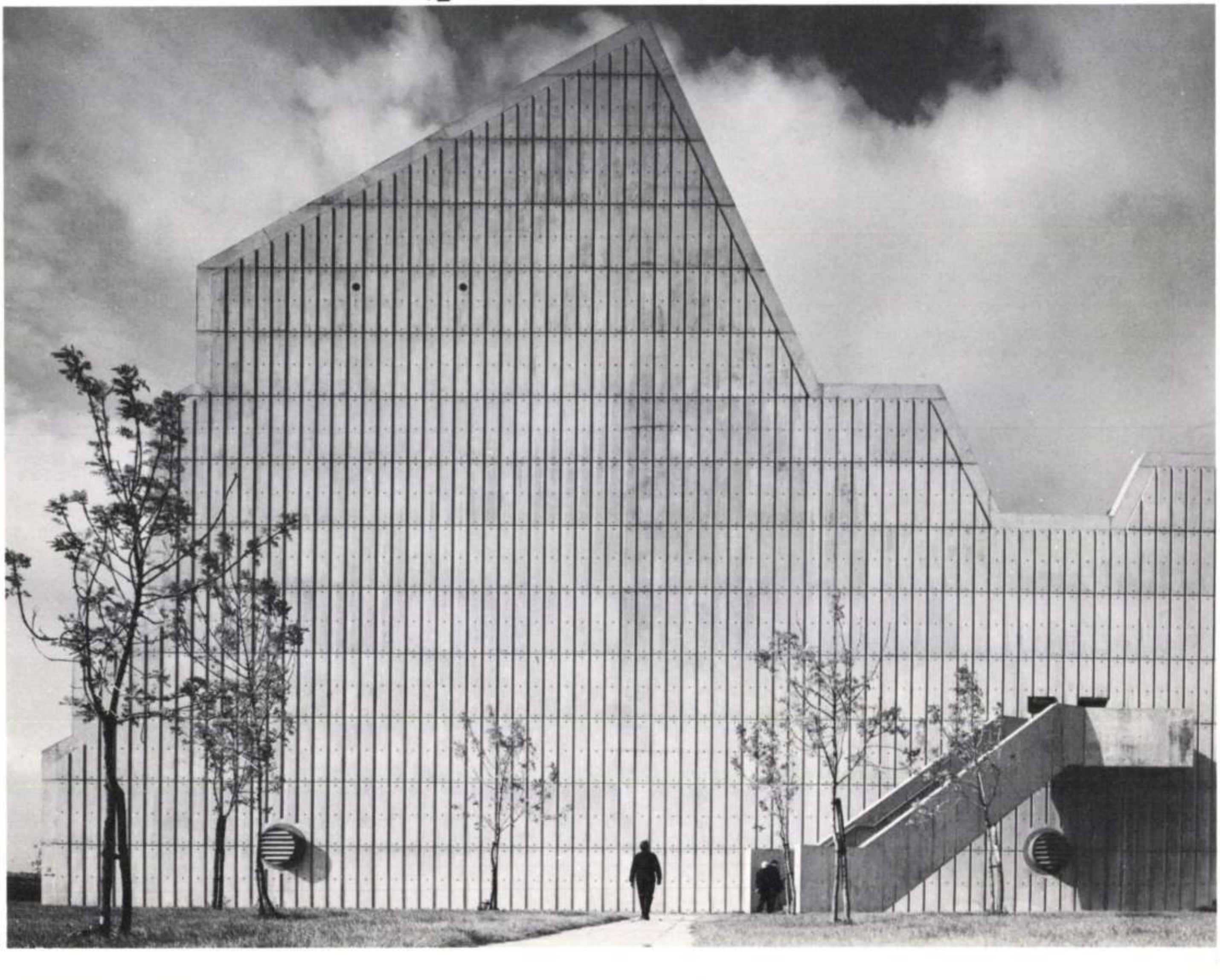

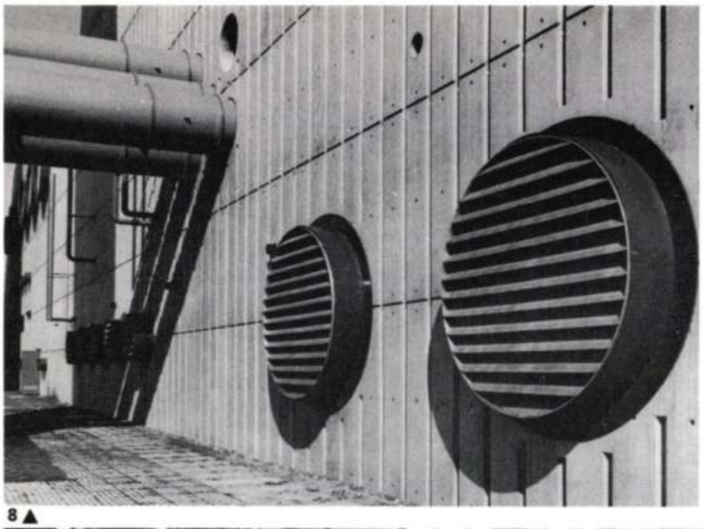

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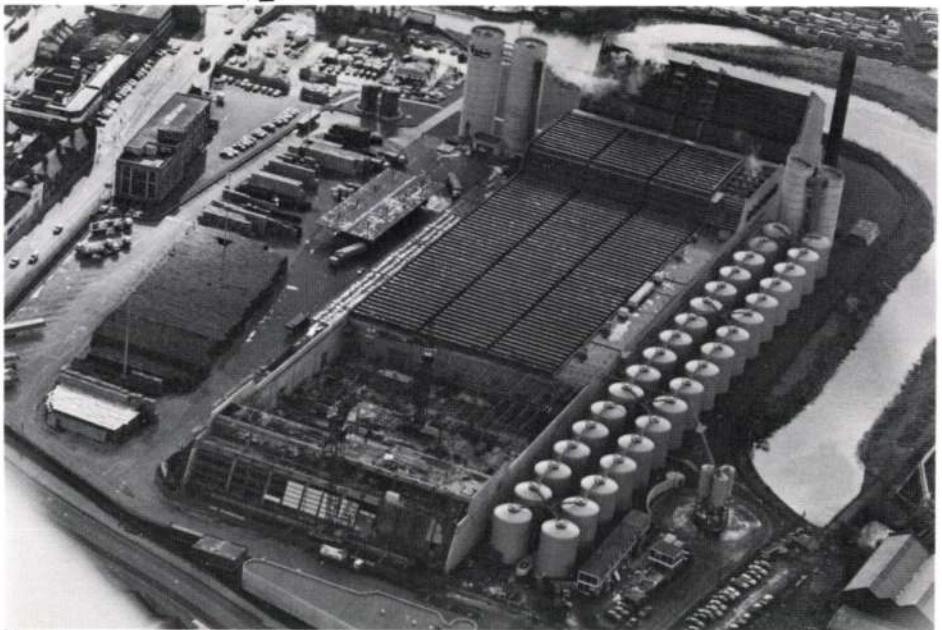

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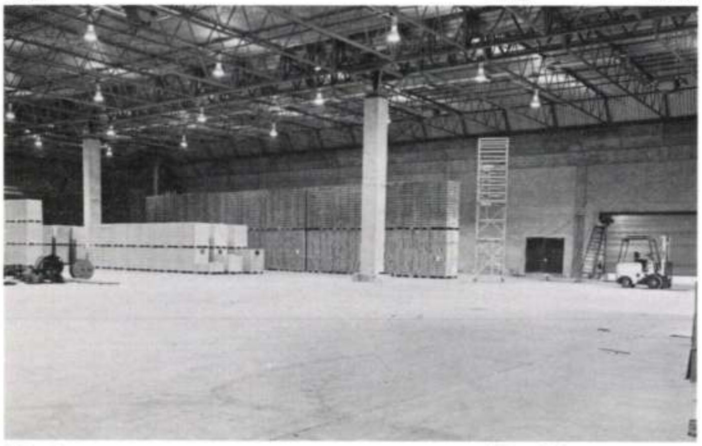

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Fig. 8
Ventilation louvres on the concrete façades are strongly featured and brightly painted
(Photo : John Donat)

Fig. 9
The energy plant is located on freestanding steel portal frames within the energy centre. The 36 m high space created pipe route and support problems which were ultimately solved by constructing a scale model
(Photo : Colin Westwood)

Fig. 10
The brewhouse plant is also supported on freestanding steel platforms. The internal ladders are for window cleaning and can be moved by means of pull ropes
(Photo : Colin Westwood)

Fig. 11
The canning hall extension is shown above under construction. It runs the width of the building, thereby imposing access restrictions which dictated the use of a steel roof over the new warehouse
(Photo : Harvest Studios)

Fig. 12
The warehouse extension is 4000 m^2 in area and allows for stacking of empty cans 8.5 m high. The roof is of steel trusses spanning 17-22 m. A space frame solution was found to be uneconomic
(Photo : Harvest Studios)

Fig. 13
The north façade, like that at the south end of the building, is totally glazed, with a step to form a terrace accessible from the canteen over the canning hall
(Photo : Harvest Studios)

Labour management is a skill in its own right and in this George Wimpey M E & C performed admirably. A labour officer was employed on site whose job it was to foresee and eliminate possible causes of discontent. He made sure, for instance, that men belonging to the same union, but working for different contractors, received comparable bonus rates. In September 1972, there was a seven-week building workers strike in the country but at Northampton less than half of this time was lost due primarily to Wimpey's skill in labour management.

Stages II-IV

Despite the success of Stage I, Carlsberg decided in 1974 to establish their own management team for subsequent stages of development. The Carlsberg Project Management (CPM) was therefore set up as soon as the second stage commenced. This organization consists essentially of an appointed project manager, resident on site, who is advised by a management team consisting of the project leaders from each of the consultancies. Management decisions are relayed to the consultants by these design leaders and to the contractors by the resident engineers who thereby play an executive role in the project. Liaison with Carlsberg's production team is through their technical manager who attends fortnightly management meetings as part of CPM.

CPM have used the basic management contracting principle of employing several direct contractors rather than one main contractor with several sub-contractors and up to 18 direct contractors have operated on site simultaneously during Stages II, III and IV. Generally however, we have tried to rationalize the contract packages such that a maximum of four direct contractors work in the same geographical area at any one time, these contractors being structural, process, mechanical and electrical.

During Stages II, III and IV Ernest Howard & Son have been responsible to the project manager for all financial matters. They have prepared tender and contract documents for all aspects of the work including the process work. Contracts for building and mechanical work have been let on the J C T conditions and for electrical and process work on the I Mech E Model Form A. Under the CPM organization the quantity surveyors are responsible for the preparation of purchase orders and the settlement of final accounts. They are also responsible for all aspects of cost control. In Stage I responsibility for this was shared by Ove Arup & Partners and CPDT with neither having responsibility for overall cost control.

Compared with the single cost plan for Stage I, 26 have been prepared for the different sections of work for Stages II-IV thus giving an indication of the fragmented nature in which these stages have been initiated by Carlsberg.

CPM pre-order long delivery or short supply items before the relevant contractor is appointed in order to maintain tight programmes as did George Wimpey in Stage I. This has worked very well during the past few years partly because of the ready availability of building materials.

The programming of all site activities for Stages II, III and IV has been Arups' responsibility. CPM has never favoured the use of sophisticated programming techniques. Instead, conventional bar charts have been produced for each contract package and these programmes co-ordinated on site. The emphasis has been on flexibility of intermediate completion dates to maintain meaningful targets.

Before starting on any particular stage of development, master programmes have been produced to show normal, accelerated and crash completion dates. In these days of high inflation, the accelerated programme has always proved to be the most economic, so this has been adopted by Carlsberg and maintained.

The CPM organization currently employes 11 people on site including resident engineers, quantity surveyors and secretaries which compares very favourably with the Stage I organization.

The method of management used by CPM is not uncommon in the petrochemical industry. What is unusual, however, is the application to a major industrial project with a very significant architectural content.

The bringing together and motivation of all parties in the building process is key to the success of the system and this has to be done on site where the end product is created. The project manager must therefore move to site on a full-time basis after the completion of scheme design and the appointment of the first contractor. It is important that he has established authority to control not only site activities but also basic design decisions from this point onwards. Good communication is essential and in Northampton monthly information meetings are held during the period of design development to explain to the appropriate contractor not only design progress, but also design philosophy. These meetings are in addition to the conventional site progress meetings. Most people in the industry want to see good quality work within pre-planned and agreed programmes. It is our experience that by bringing all parties together, by communicating well and by correct motivation, this can be made to happen economically.

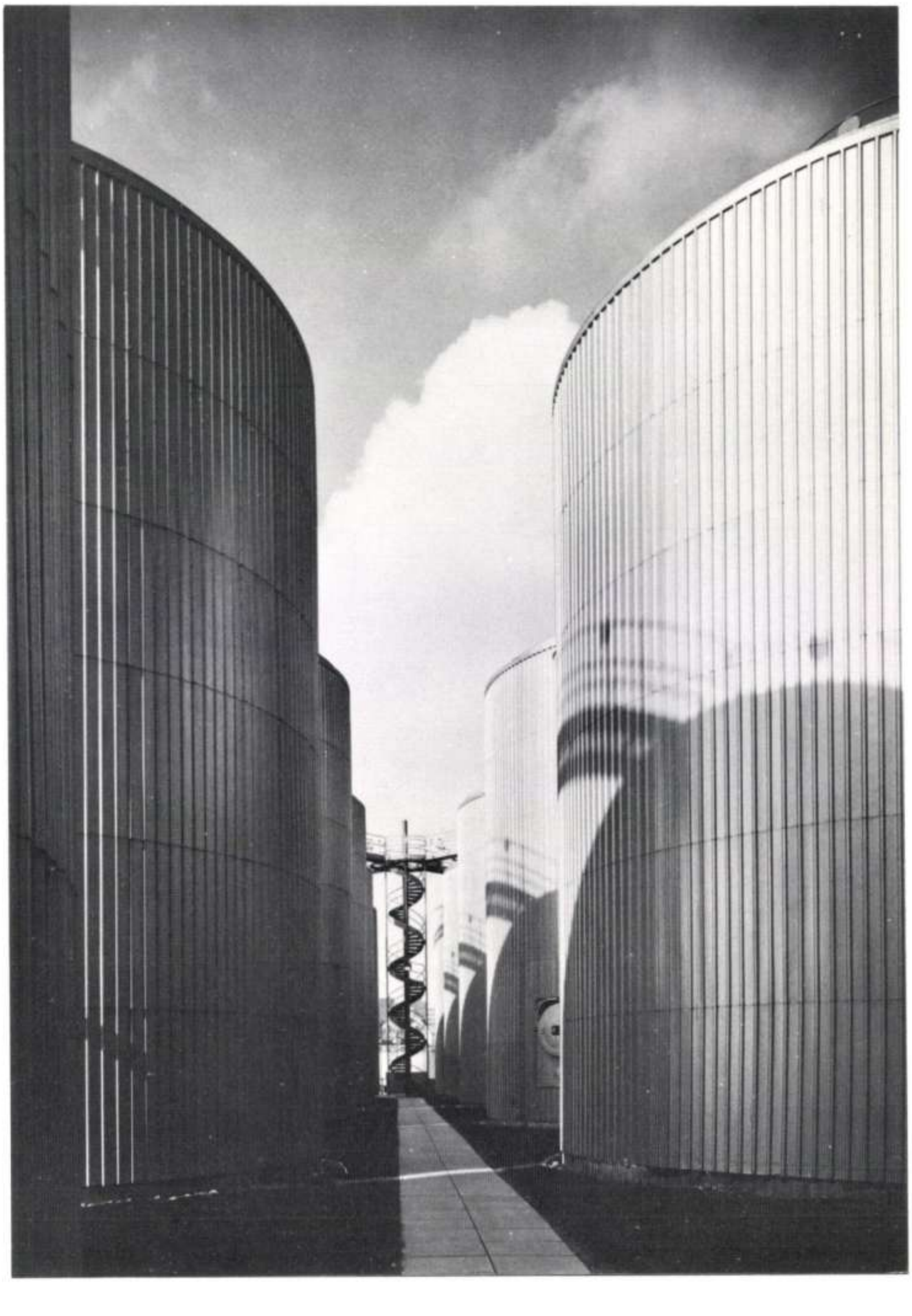


Fig. 14
34 lager tanks for secondary fermentation are located between the brewery building and the river, with each tank containing about one million pints
(Photo: Colin Westwood)

Fig. 15
The brewery building is 250 m long and 70 m wide and is split into seven sections by lateral expansion joints. The brewhouse and energy centre are located at the southern end of the site along with the malt silos and water tanks. This is followed by the fermenting area and packaging with the new canning hall at the extreme north
(Photo : Harvest Studios)

Fig. 16
This is 'Carlsberg Northampton', with the brightly painted plant in the energy centre and brewhouse illuminated by night within a concrete frame
(Photo : Colin Westwood)

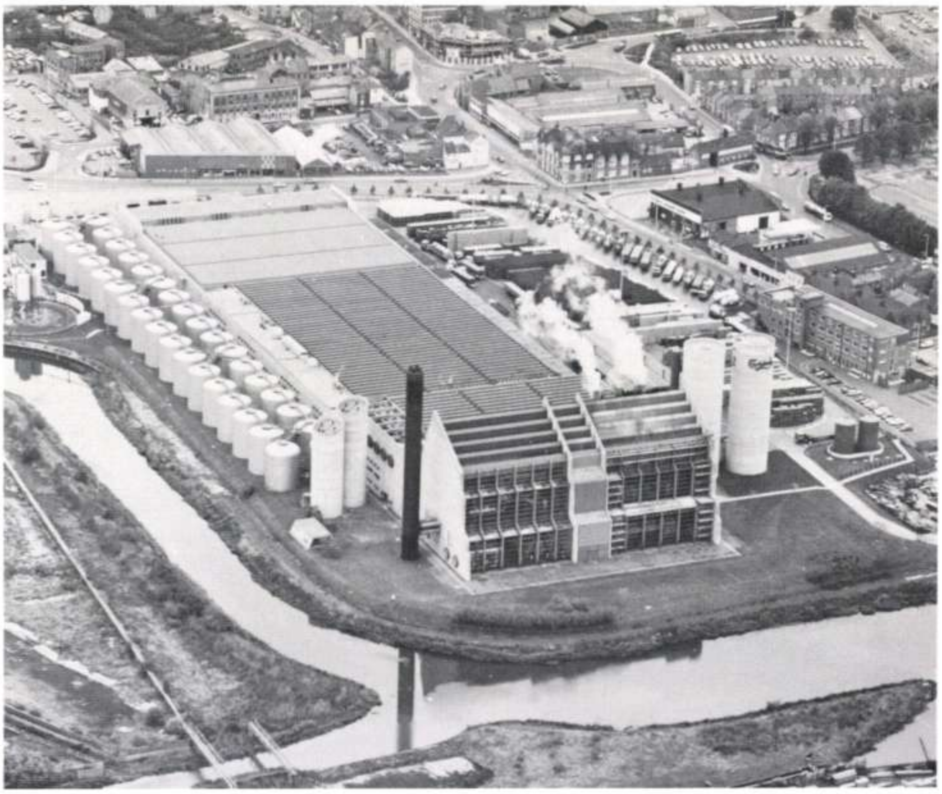
Credits:

Client (Phases 1-4):
Carlsberg Breweries Ltd.

Architect (Phases 1-4):
Knud Munk

Main contractor (Phase 1):
George Wimpey & Co. Ltd.

Main contractor (Phases 2-4):
Kyle Stewart (Construction) Ltd.



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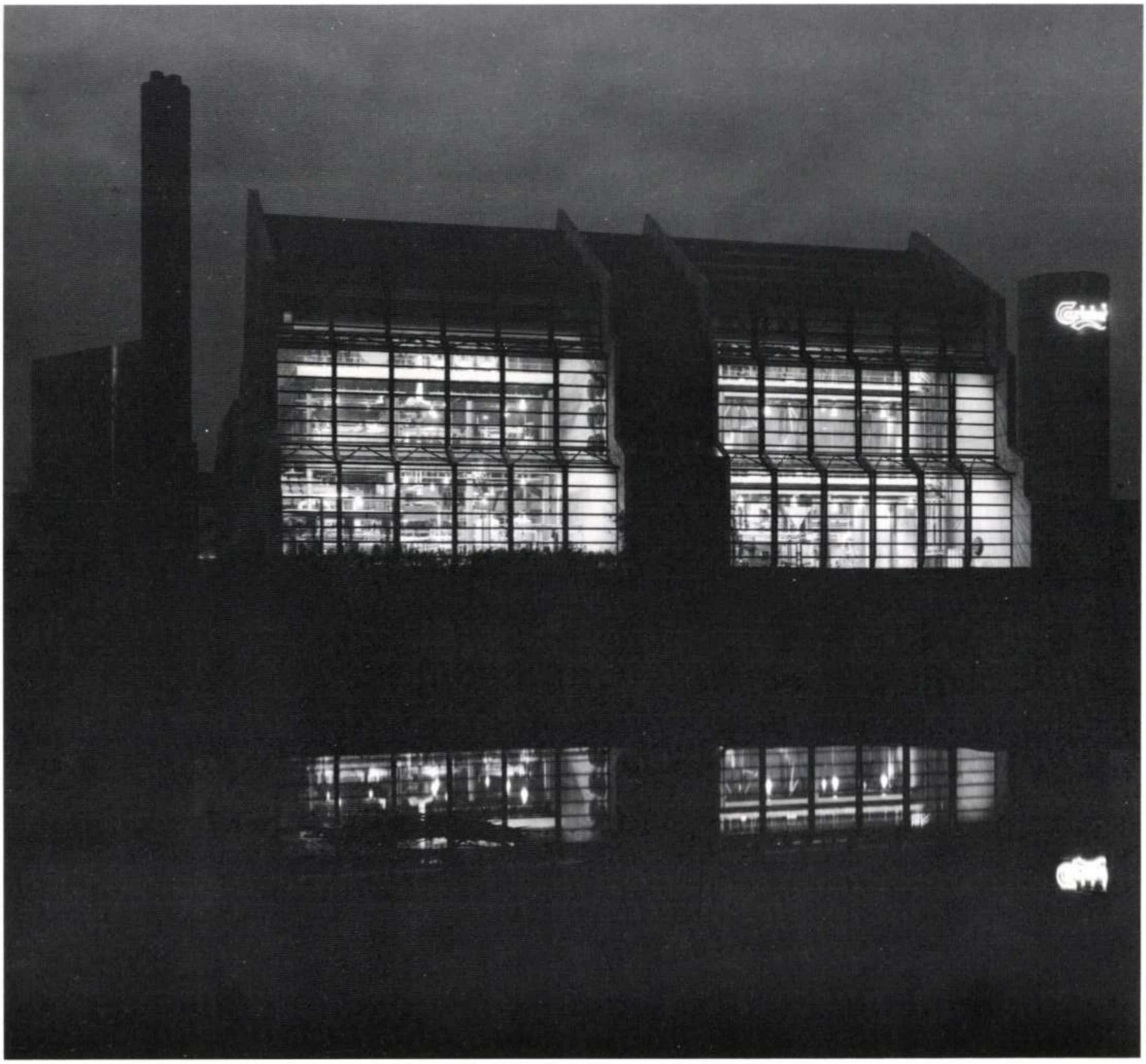


The College of Law Social Block, Guildford

Ian Wattridge

Architects:
Scott, Brownrigg and Turner

The brief was to design a building with the primary function of providing simple and inexpensive meals for a maximum of 500 students. In addition to the refectory and the back-up facilities of kitchen, servery and storage, the building was to include a reading room for 250 people, a games room, a coffee lounge and a small television room.

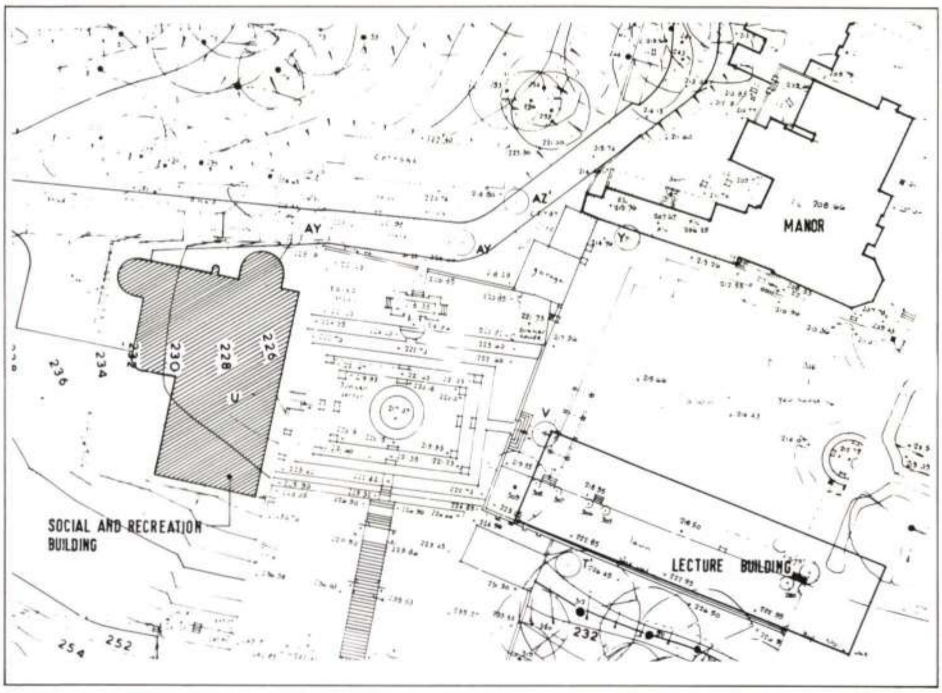


Fig. 1
Location plan

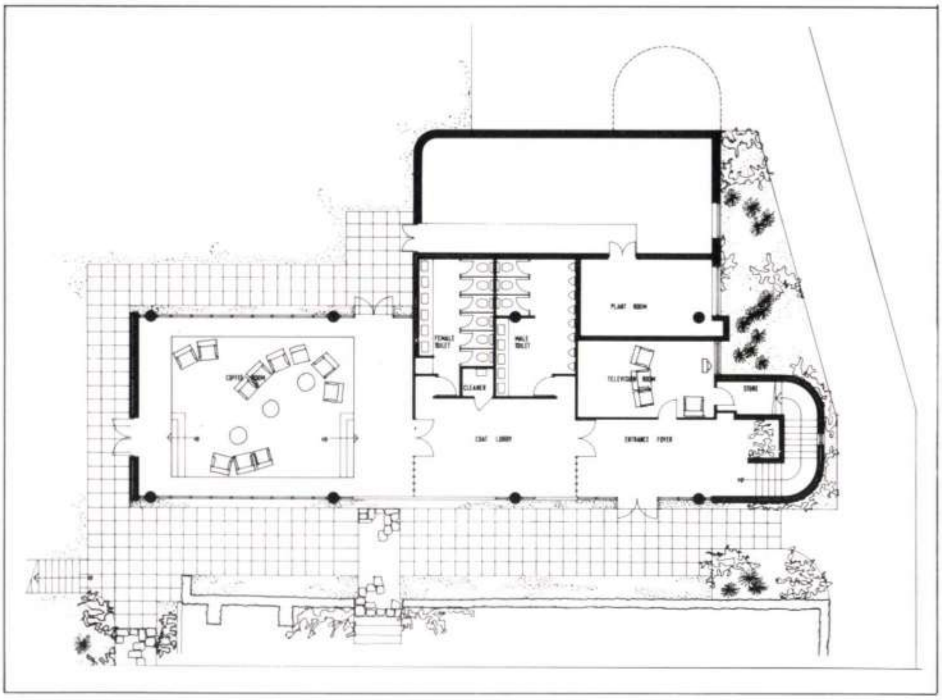


Fig. 2
Ground floor plan

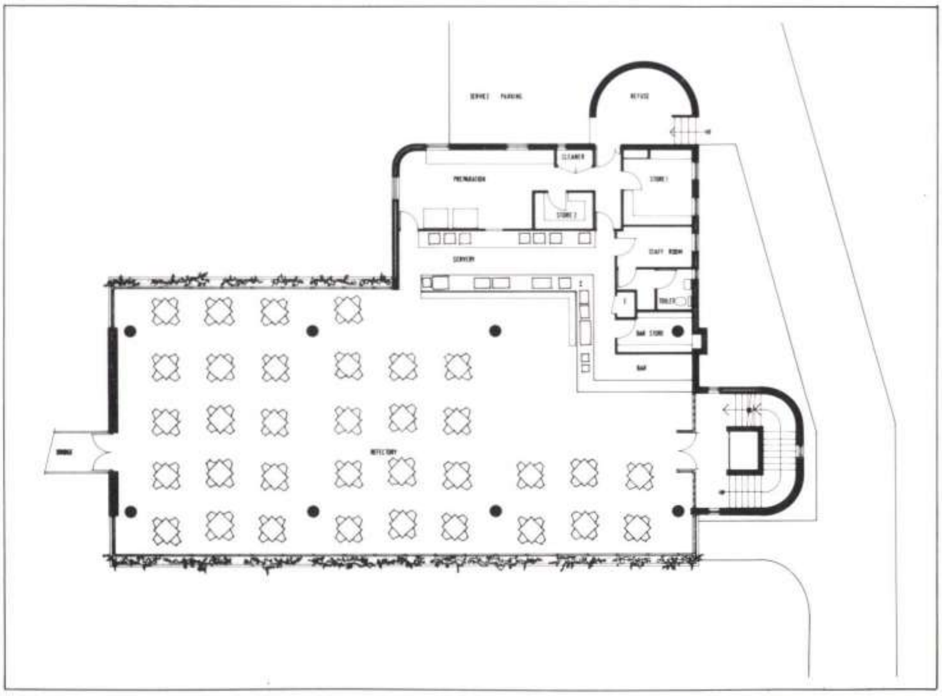


Fig. 3
First floor plan

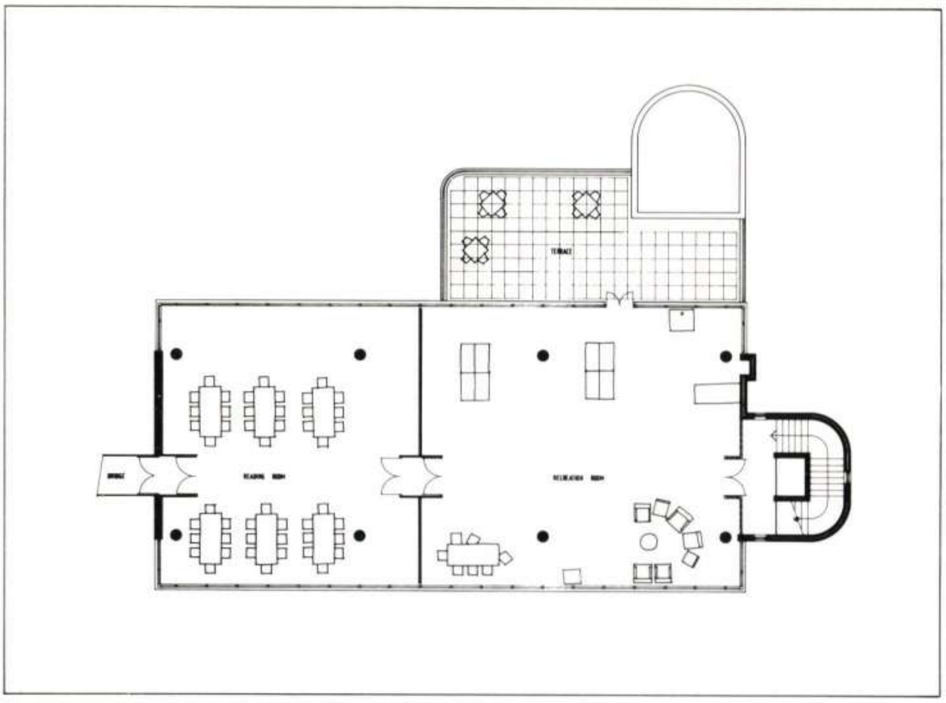


Fig. 4
Second floor plan

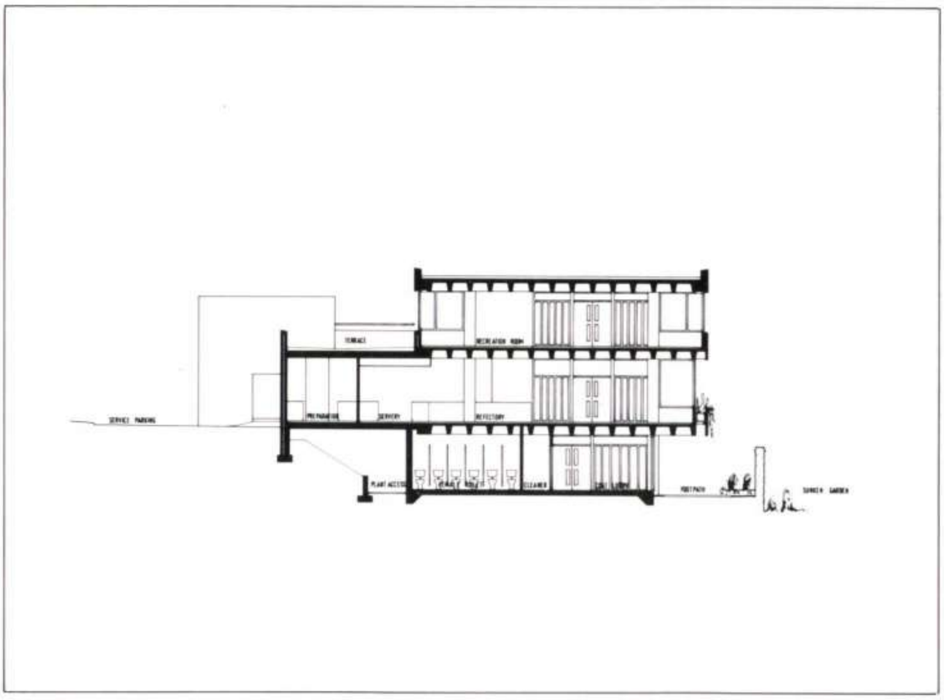
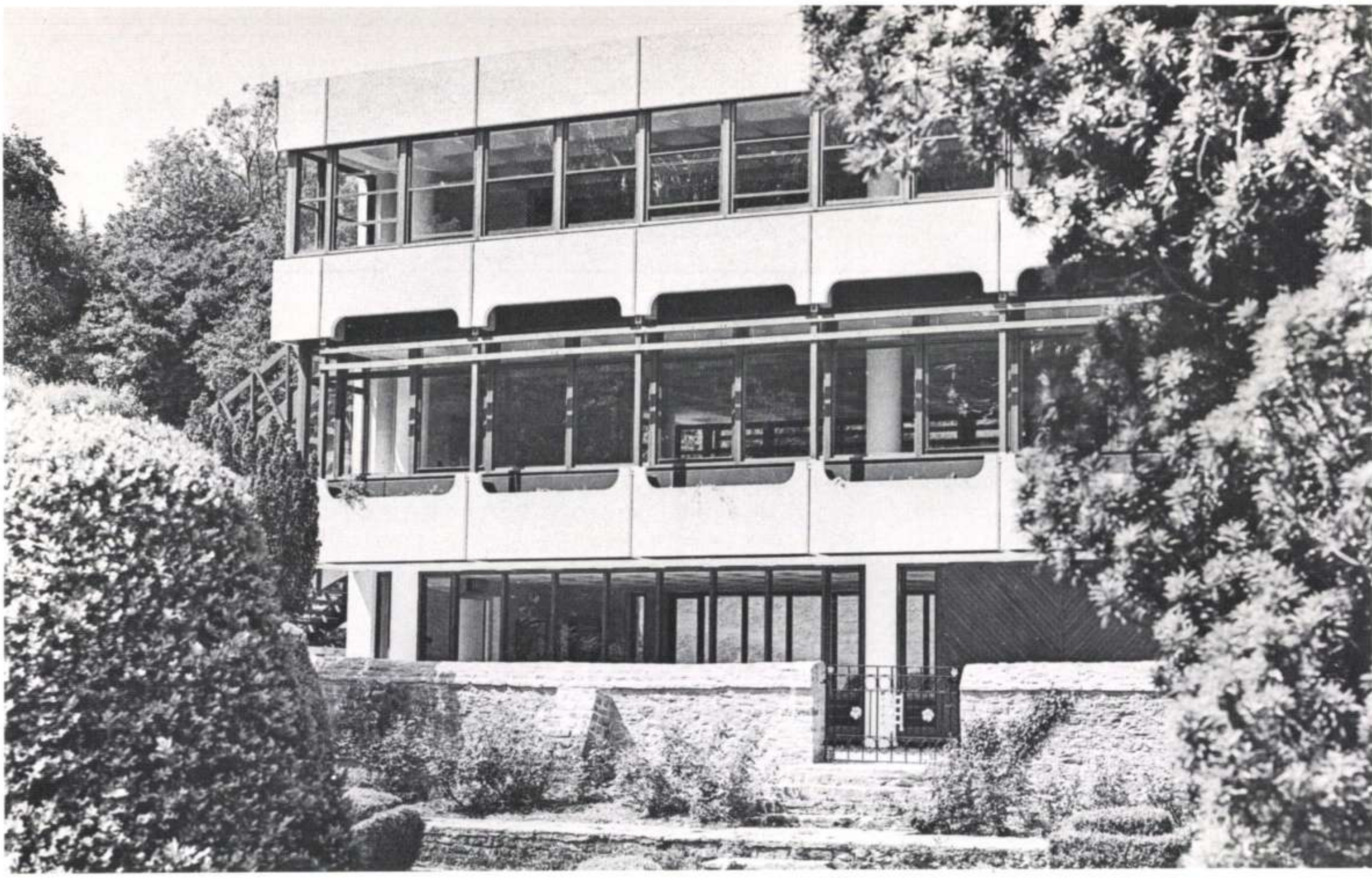


Fig. 5
Section through building

Fig. 6
First floor refectory
(Photo : Colin Westwood)



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Figs. 7-8
Front/east elevation
(Photos: Scott, Brownrigg & Turner)

Figs. 9-10
Rear/west elevation
(Photos: Scott, Brownrigg & Turner)

Fig. 11
South end down to the gardens
(Photo: Scott, Brownrigg & Turner)

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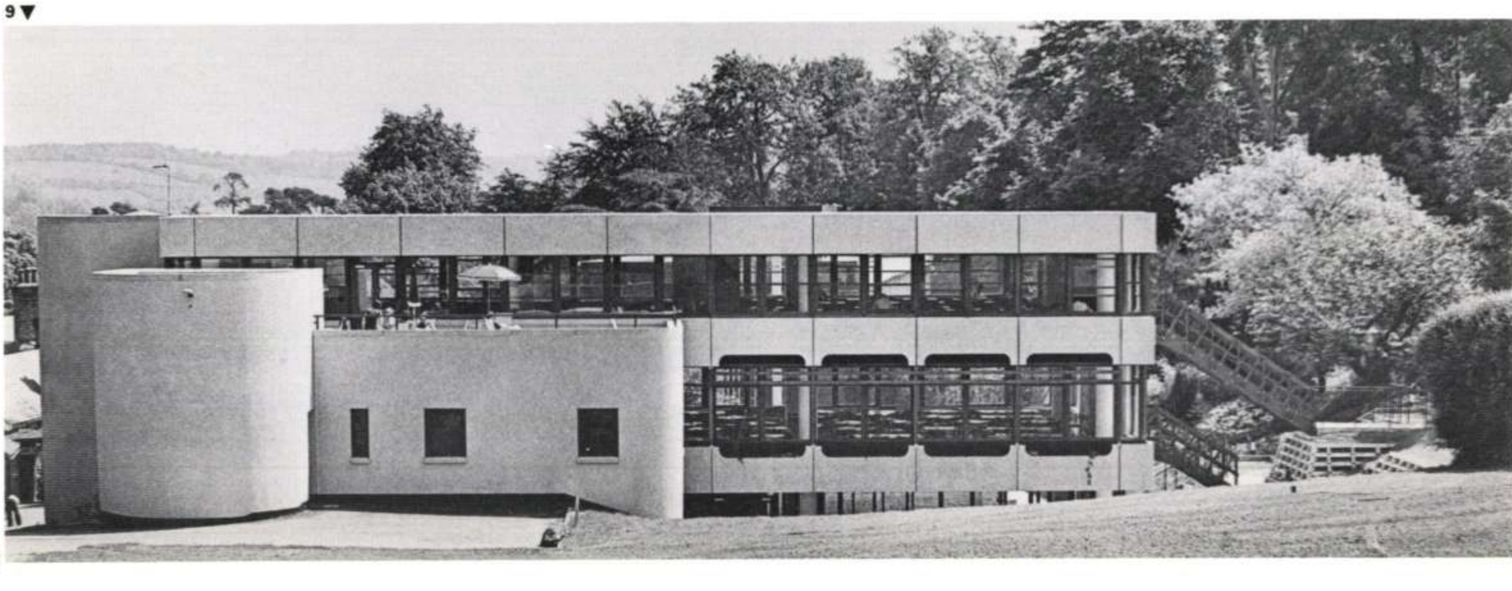


College of Law Social Block

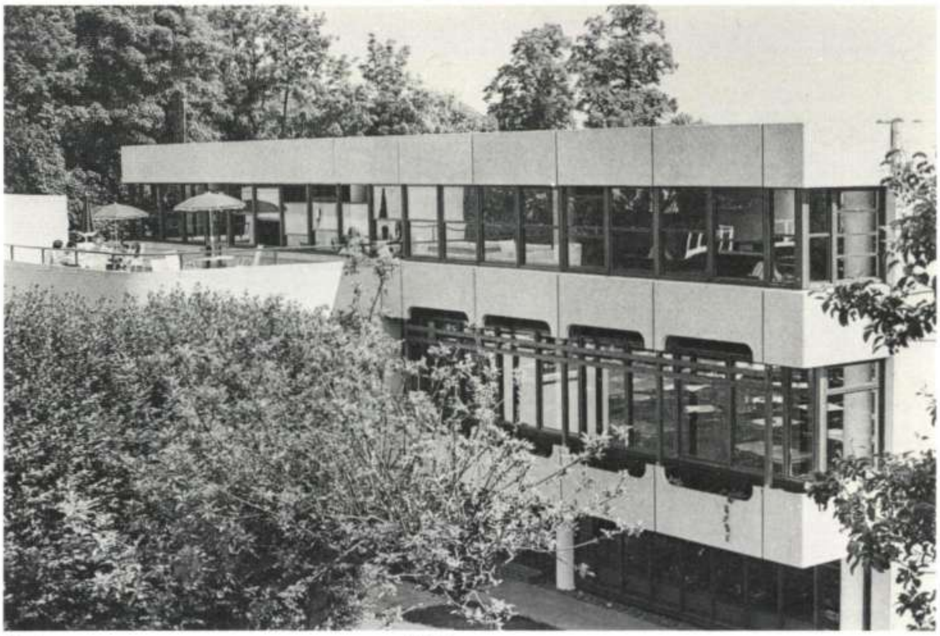
The size, siting and general arrangement of the building were largely dictated by the budget of around £300,000.

The site was chosen for its close proximity to the Manor House, the lecture block and car park, and the building was orientated to take advantage of the exceptionally attractive formal gardens and distant views.

The structure is reinforced concrete with waffle floor slabs and circular concrete columns. Cantilevers to the east and west support elevations of precast concrete and extensive glazing. At first floor level the glazing is recessed to accommodate an external planting trough and trellis screen.

The concrete roof is surfaced with asphalt with insulation and shingle finish. The roof to the kitchen is paved for use as a terrace from the games room.

The building contract which included the construction of a large car park, part of the access road and extensive landscaping works commenced in January 1976 and was completed in mid-December, 1977.



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Credits:

Architects and planning consultants:
Scott, Brownrigg and Turner

Quantity surveyors:
J. B. Marks & Partners

Services consultants:
Steensen, Varming, Mulcahy & Partners

Tsuen Wan wind tunnel test

David Croft

Architects: Choa, Ko and Partners in association with Lee and Zee Associates

Introduction

The Tsuen Wan Estates Development (Figs. 1 and 2) is to be sited on the 5.5 ha podium deck above the Mass Transit Railway depot at Tsuen Wan, Hong Kong, and consists of residential tower blocks, schools, banks, shops and other public amenities. It will provide accommodation and facilities for 20,000 people.

There are 17 residential blocks with a total gross floor area of 215,000 m^2. The blocks are of cruciform shape in plan and vary between 28 and 30 storeys high. The structure of each block consists of reinforced concrete shear walls and floor slabs, supported on a grillage of 2 m deep beams that transmit the loads onto columns which pass through the railway depot below.

In Hong Kong, design for wind loading normally must comply with the Hong Kong Building Regulations which, although somewhat simple in their approach, generally lead to quite sensible design values. However, in view of the size and nature of the project it was considered that a more rigorous approach was required in this case and we therefore recommended that a wind tunnel test should be carried out. The instruction to proceed was given by MTRC in December 1978 and the tests were carried out during the period January/March 1979 by the Department of Aeronautical Engineering at Bristol University.

Description of testing method

The model

The aim of a structural wind tunnel test is to determine the design values for wind loads on the building under consideration. The procedure is to first make a scale model of the projected development which need not be an exact replica of what is to be built (generally this is not possible anyway during the initial design stages when the design information is required), but should contain those elements that will have a significant effect. Some simplification is indeed of benefit when interpreting the results as it is less likely that significant factors will be obscured by superficial effects. Similarly, the surrounding area need only be modelled in a very generalized way.

The model is then mounted in the wind tunnel on a turntable so that wind from all directions can be modelled. The size of the model is naturally limited by the dimensions of the wind tunnel as the 'blockage factor' (i.e. the ratio of the area in elevation of the model to the area of cross-section of the tunnel) must be kept sufficiently low, otherwise the edge effects of the sides of the tunnel become significant.

Wind simulation

Under the design conditions the wind speed is not constant but fluctuates rapidly in a random manner as shown diagrammatically in Fig. 3. These fluctuations or gusts are best dealt with statistically (Fig. 4) and the wind speed can, for this purpose, be defined in terms of three parameters:

Mean hourly wind speed
Turbulence intensity
Power spectral density

Traditionally wind records are expressed in terms of three-second gust speeds (which is the response time of the anemometer at a

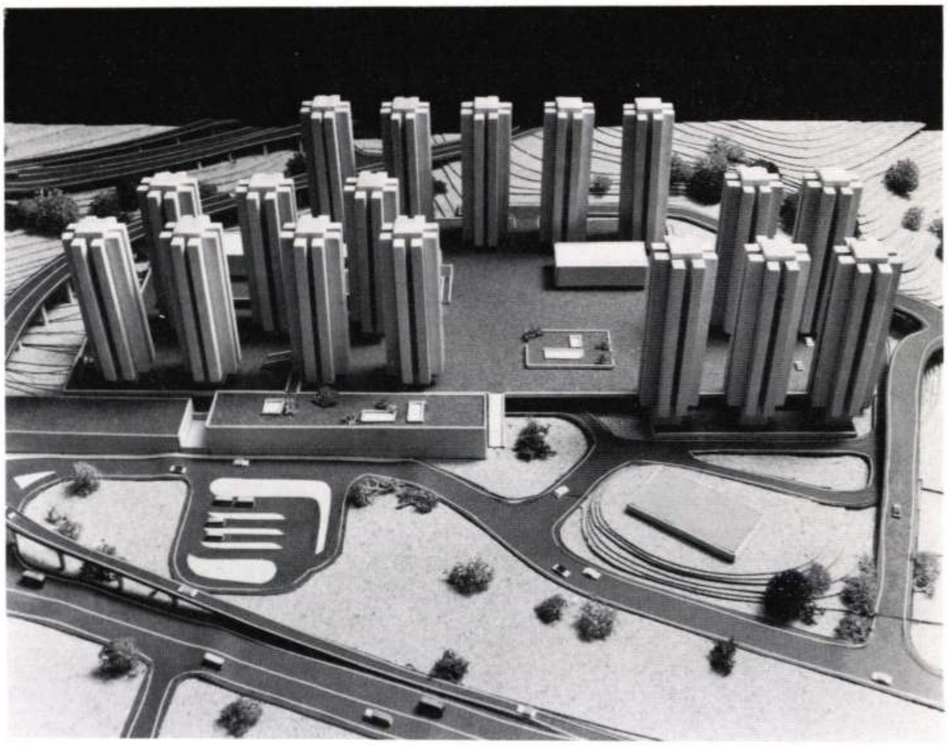


Fig. 1
Architectural model (Photo: Neil Farrin)

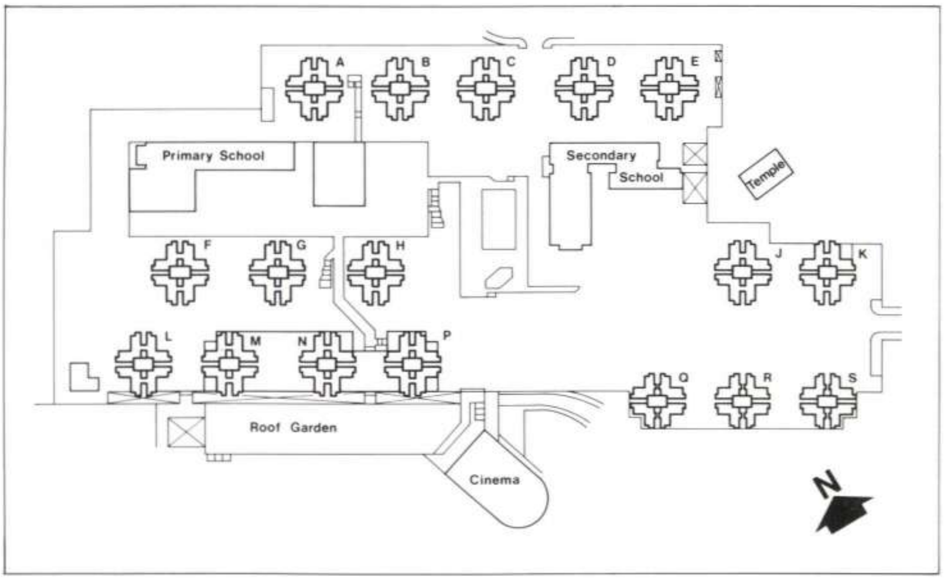


Fig. 2
Site plan

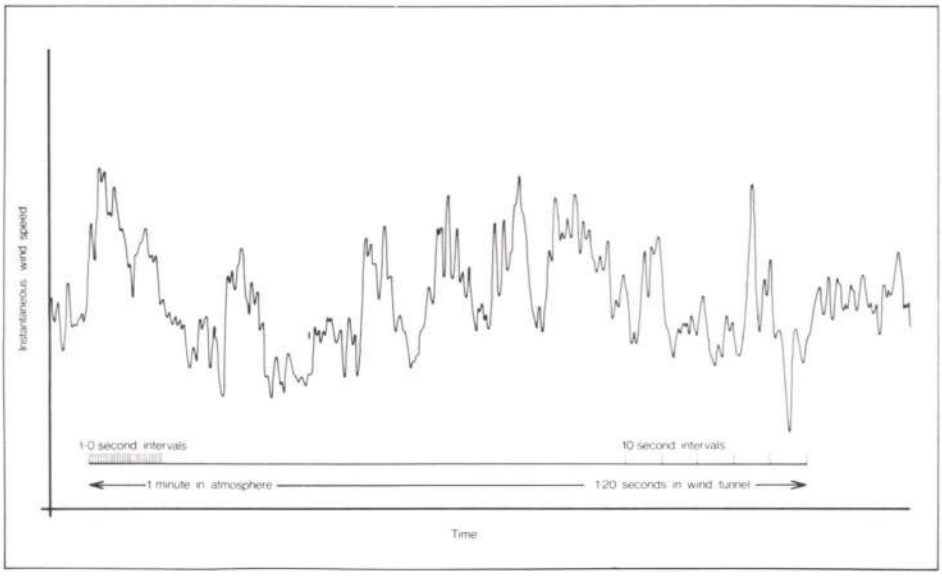


Fig. 3
Diagrammatic trace of variation of wind speed and pressure with time

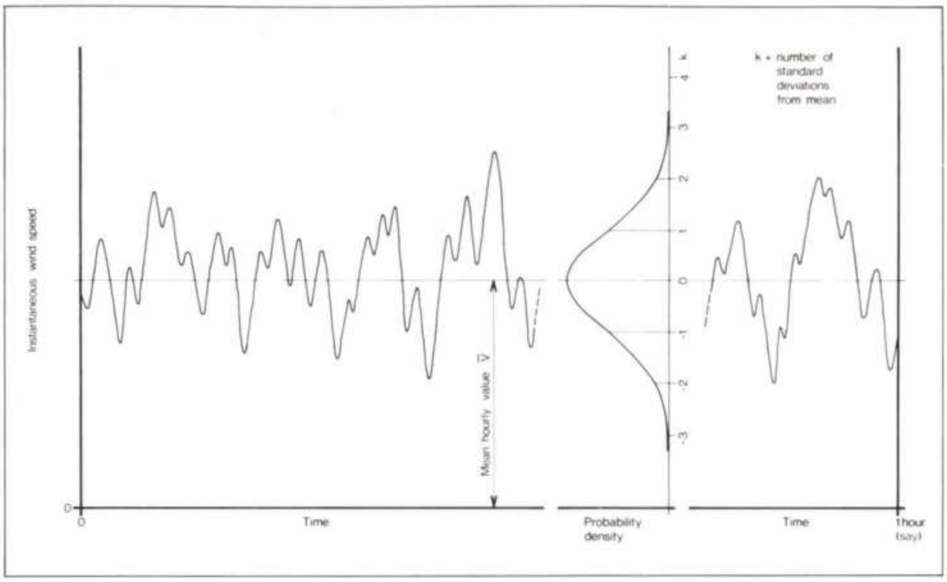


Fig. 4
Illustration of probability density function of fluctuating component

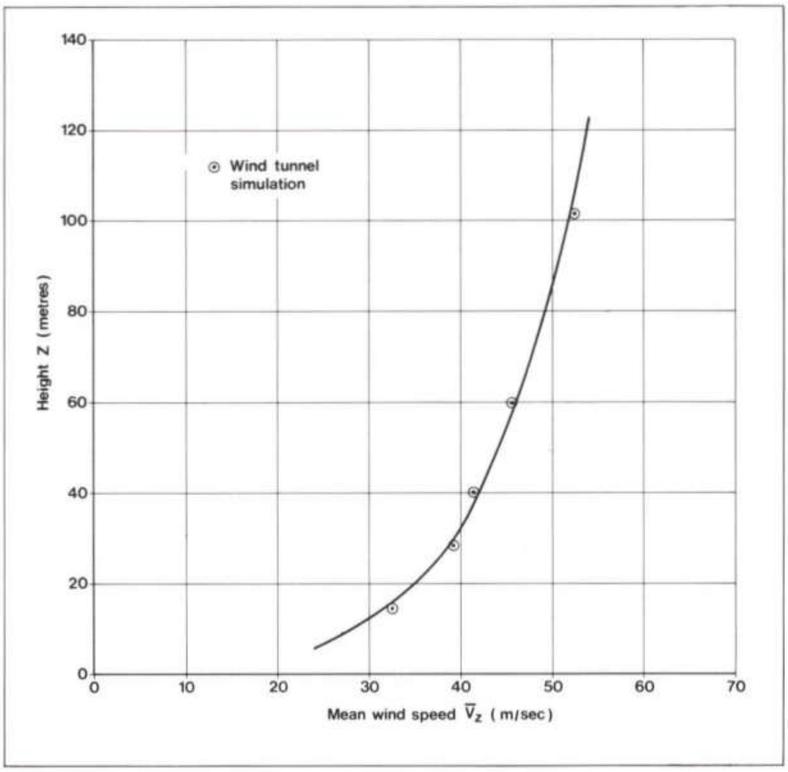


Fig. 5
Upstream wind velocity profile

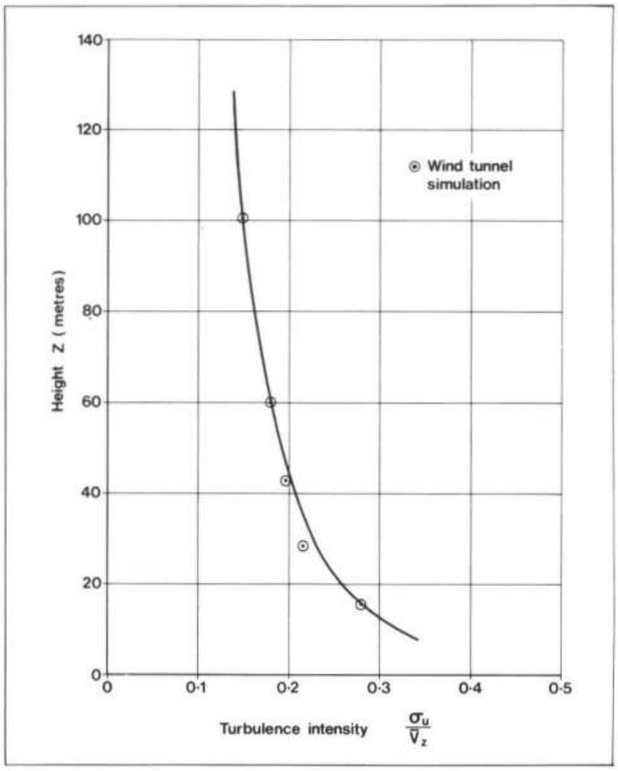


Fig. 6
Upstream turbulence profile

typical meteorological station) or mean hourly wind speeds which are the average of the three-second values over a period of an hour. However, when considering the effects on buildings, a 10 minute period is sufficiently long but, as this is in practice very close to the mean hourly value, the latter is normally used for convenience. As a result of the friction over the ground the mean wind speed $\overline{V}_z$ increases with height (Fig. 5).

The turbulence intensity (I) is a measure of the overall gustiness and is defined as follows:

$$I = \frac{\sigma_u}{\overline{V}_z}$$

where σu is the standard deviation of the instantaneous wind speed about the mean value $\overline{V}_z$. The turbulence intensity normally decreases with height (Fig. 6).

The power spectral density function describes how the energy in the gusts is distributed over the range of frequencies and is conventionally plotted, as in Fig. 7, as the product of the spectral density S and the frequency n divided by the variance $\sigma_u{}^2$ against frequency.

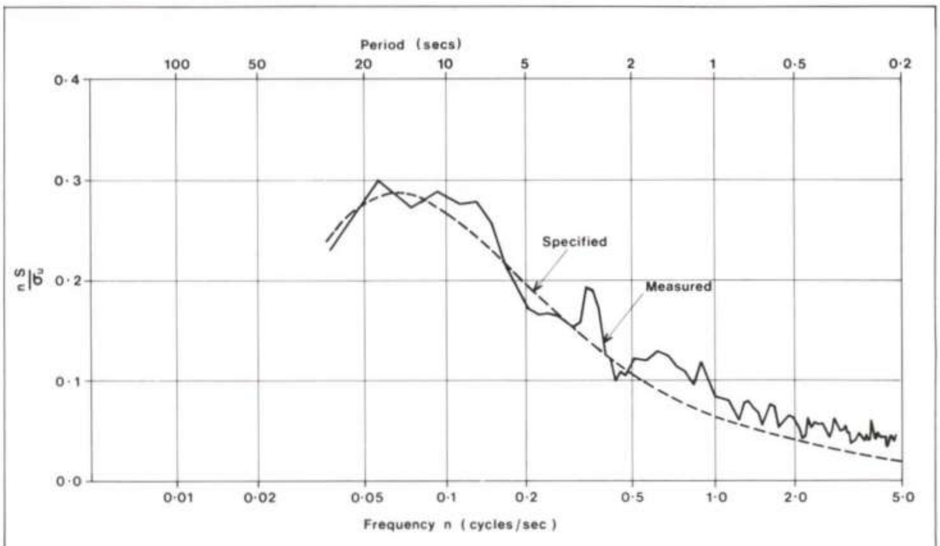


Fig. 7
Upstream power spectral density

Measurement
Having set up the wind tunnel, the various effects can then be measured in a number of ways:

Anemometer readings
Wind speeds on any point around the model can be measured using a hot-wire anemometer mounted on a probe, which is sufficiently small not to significantly disrupt the air flow. These readings, however, are not of direct value for determining wind loading on buildings and are of more use in assessing environmental or local effects.

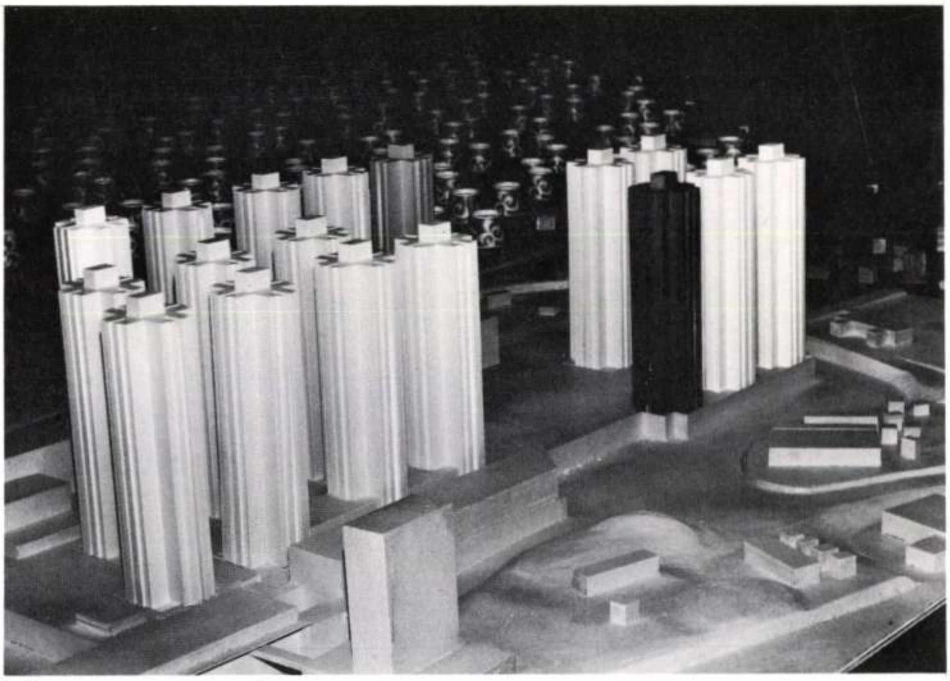
Pressure readings
The model can be fitted with pressure tapping points connected to a measuring device fixed below the base of the model and these will measure the air pressures immediately adjacent to the tapping points.

Balance readings
The resultant forces and bending moments acting on the structure can be measured by mounting the model, or part of it, on a balance fixed below the base.

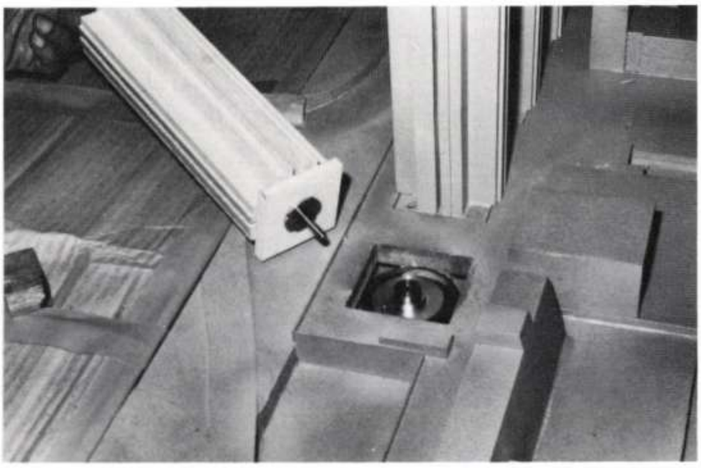
Fig. 8
Wind tunnel model
(Photo: Bob Care)

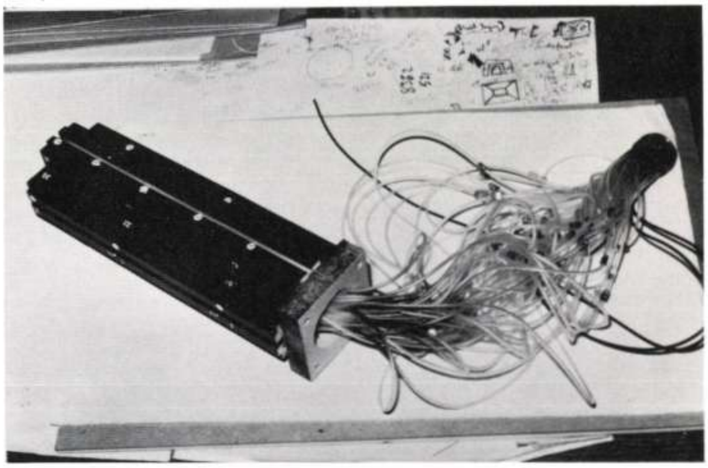
Fig. 9
Balance detail
(Photo: Bob Care)

Fig. 10
Pressure tapping points
(Photo: Bob Care)



8▲ 9▼ 10▼





In each case these readings will fluctuate in a similar manner to the upstream wind (Fig. 3) and are therefore also interpreted statistically. In the wind tunnel test the readings are recorded by a mini-computer which automatically calculates and stores the mean and standard deviation values.

Averaging interval
It is apparent from Fig. 4 that the shorter the time interval taken, the higher the maximum gust values will be and it is therefore necessary to determine an 'Averaging Interval' that is appropriate to the way the results are to be used. Thus, when considering wind loading on the building as a whole, only those eddies that are sufficiently large to act on all the building at the same time need to be considered and these are associated with a longer averaging interval. This is the basis for *CP3 Chapter V Classes A, B and C* which relate to the size of the building or part of the building under consideration.

Time scale
Just as a length scale can be used for the model, a time scale is also used (in this case 1:50). Thus, a 10 second gust acting on the real structure is equivalent to 0.2 seconds in the wind tunnel. This has the advantage that, as the readings have to be interpreted statistically, sufficiently large samples of data can be obtained within an acceptable length of time.

Design values
In order to use the results for the design of the structure it is necessary to select appropriate design values which could theoretically be done by taking the mean value plus an appropriate number of standard deviations. This approach, however, leads to a difficulty because, although in some areas the pressures can be considered as normally distributed with respect to time, in other areas they cannot[1] with the result that the required number of standard deviations varies from point to point. An alternative approach suggested by Lawson[2], and the one adopted in this case, is to take values which are exceeded in the wind tunnel for a given proportion of the time. By applying probability theory it can be shown that if the mean wind speed in the wind tunnel test corresponds to the design mean hourly wind then the design gust value should be that which is exceeded by 0.05% of the readings in the test.

There has been much discussion in recent months on wind tunnel theory as applied to building structures. Since these tests were carried out, significant advances have been made[3] and if we were to do the tests again we would probably treat this aspect somewhat differently.

Test details

The model
A plan showing the arrangement of the Residential Blocks is shown in Fig. 2. The test model (Fig. 8) was made to a scale of 1:350 and included the 17 tower blocks, the Depot roof and the low-rise Estates Development as well as the existing buildings in close proximity to the site.

The tower blocks are of two basic designs (A and B) and vary between 28 and 30 storeys high, but the overall height of the blocks is the same. All 14 Type B blocks were therefore treated as identical as were the three Type A blocks.

The low-rise buildings on the depot roof were modelled in a simplified way in view of the fact that their design was not then finalized. This level of accuracy was sufficient for the purpose of obtaining wind loads on the tower blocks, but would not be appropriate for investigating wind effects on the low-rise structures themselves. Similarly, the modelling of the surrounding buildings was also greatly simplified as these too will obviously change with time.

The model was designed so that each of the tower blocks could be removed and replaced, either by one attached to the dynamic balance below (Fig. 9) or by one fitted with pressure tapping points (Fig. 10).

Wind parameters
For the design of the Residential Blocks a return period of 50 years was chosen and the necessary wind parameters were derived using the ESDU formulae[4]. The specified mean hourly velocity at 10 m height was 28 m/s and the specified mean velocity, turbulence and power spectral density are shown in Figs. 5-7. Also plotted for comparison are the values measured in the windtunnel. In *CP3 Chapter V* terms this would be equivalent to a basic wind speed of 68 m/s with ground roughness 3.

Averaging interval
The required averaging interval was determined using the formula given in Reference 5 and was found to be 10 seconds, based on a mean hourly velocity at mid-height of 45 m/sec. This is somewhat shorter than the

15 seconds mentioned in *CP3 Chapter V* as corresponding to Class C structures and reflects the higher wind speeds in Hong Kong compared with the UK.

Design probabilities
The design values for 10 second gusts were taken as those values which were exceeded in the wind tunnel test for 0.05% of the time.

Testing procedure
The testing procedure originally specified for the tests was as follows:

(i) Shear forces and bending moments at the base of each tower for all wind directions at 15° intervals were to be measured first using the balance.

(ii) Pressures would then be measured at 100 points on a single block for a limited number of wind directions on specified blocks. These would be identified after the results of the balance measurements had been analyzed.

As it happened, technical problems were encountered with the balance measurements both for the mean and the fluctuating values. These problems were caused by resonance of the model and support system and were partially overcome by making a much lighter weight block model to be used with the balance. This enabled satisfactory readings to be obtained for the mean forces and moments but it became apparent that significant modifications to the balance system would be necessary in order to obtain reliable values for the fluctuating components and this would not be possible within the time available.

It was therefore decided to amend the testing programme in order to get more data from the pressure readings. Pressure readings for all wind directions, again at 15° intervals, were therefore taken for Blocks C and E as it was apparent from the mean balance readings that the wind loading on these blocks would be critical. In addition, a full set of readings was also taken for Block C in its position on the podium but with all the other blocks removed.

Presentation of results
Base shear forces and moments at podium level corresponding to 10 second gusts for Blocks C and E and Block C alone were obtained by integrating the pressures over the surface of each block and the results for Block C are plotted in Figs. 11 and 12.

By comparing the gust forces and moments for these cases with the corresponding mean balance results, relationships were derived which could then be applied to the other blocks. In this way values for the 10 second gust shear forces and bending moments were obtained for all the blocks and the former are shown plotted in Fig. 13. Also shown are the corresponding values obtained from the Hong Kong wind code using a shape factor of 1.0.

The integration of the pressures and the plotting of the results was carried out on the DEC-10 computer in the London Office of Ove Arup and Partners. The data was transferred from Bristol to London by means of punched paper tape.

Results of the tests

Block C alone
The pressure readings taken for Block C in its position on the podium but with the other blocks removed served as a base run and enabled the effects of the shape of the individual blocks to be separated from the effects of the inter-action between them. The base shear force is shown plotted in Fig. 11 and the corresponding values obtained from the Hong Kong wind code and from *CP3 Chapter V* (assuming a basic wind speed 68 m/s and Roughness 3 Class C) are also plotted for comparison. From these

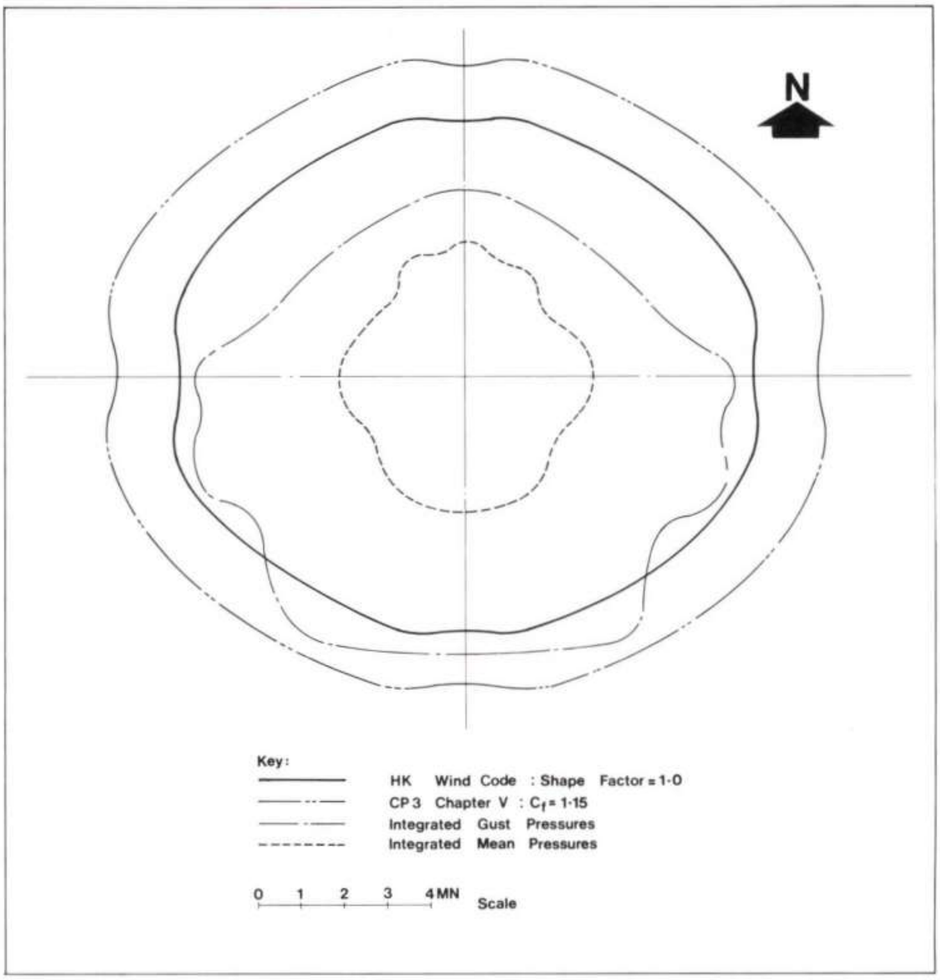


Fig. 11
Block C alone – base shear forces

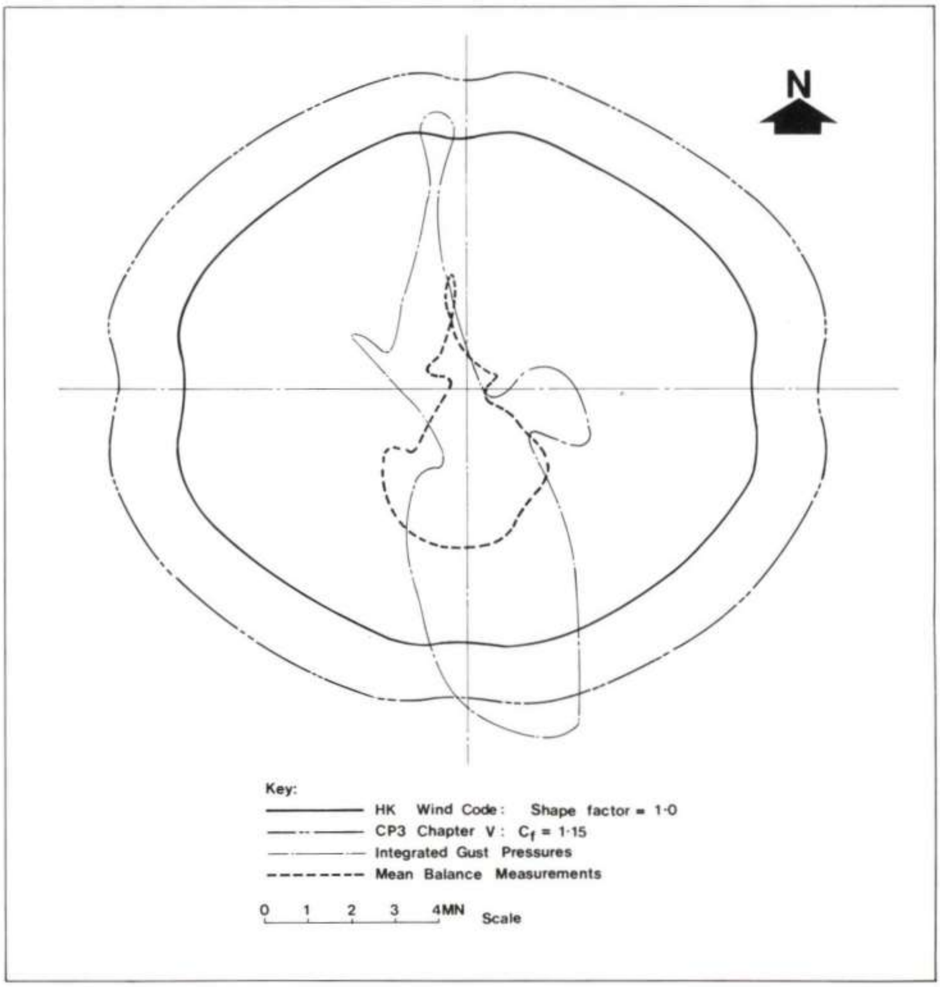


Fig. 12
Block C – base shear forces

results the following conclusions were drawn:

While the mean pressures are found to be reasonably constant for all wind directions, the gust pressures are significantly higher for winds from the north. This would appear to be due to the fact that the site is much more exposed to the north than to the south and that on that side the podium is at the level of the surrounding ground.

The HK wind code appears to be conservative for south winds but to under-estimate the wind loading from the north. As the south direction is more typical of the urban conditions in Hong Kong, these results indicate that the HK code forms a reasonable basis for design in most cases.

It was found that the pressures on most faces were negative for any wind direction and that the resultant forces on the structure were primarily due to these suctions rather than by positive pressures on the windward side (Fig. 14).

Comparing the results for the shear forces and bending moments it was apparent that the resultant wind force acts at a lower level than implied by the codes of practice which assume that the pressure at each level is proportional to the square of the velocity at that level in the undisturbed airflow.

From the typical pressure readings up selected faces of the building (Fig. 14) it would seem to be more realistic to assume that the pressures are on average uniformly distributed up the building. The physical explanation of this phenomenon is that if the pressures did vary in the way the codes of practice imply, then the air would flow towards the areas of low pressure thereby evening out the differences in pressure.

Blocks C and E

The base shear forces for Block C with the other blocks in place are shown in Fig. 12 and the bending moments show a similar pattern. It is apparent that the shielding effects of the adjacent blocks substantially reduce the wind load in the E-W direction. In the N-S direction, however, the wind forces are increased and this is due to the fact that the wind has to pass the five blocks A-E in which the gaps between them amount to less than half of the total width. The airflow therefore tends to pass around the outer blocks, thereby increasing the suction on the leeward side and hence the resultant forces. On Block E the wind force is enhanced for wind from the east due to the presence of Block D downstream which increases the suction on the leeward face. In each case, however, the same relationship between moment and shear forces as for Block C alone was found.

Proposed design loads

As a result of these factors, it was therefore proposed that each block should be designed for a uniform pressure up the face of the building calculated from a basic pressure of 2.7 kN/m^2 multiplied by force coefficients as follows:

Block	Type	Storeys	Cf N-S	Cf E-W
A-E incl	B	30	1.25	1.25
F G H L	B	29	1.1	1.15
J K	B	30	1.1	1.1
M N P	B	28	1.15	1.1
Q R S	A	30	1.1	1.1

The same pressures were also to be applied to the roof plantrooms.

The uniform basic pressure of 2.7 kN/m^2 is equivalent to calculating the total force in accordance with *CP3 Chapter V* Roughness 3 Class C with a basic wind speed of 68 m/s and then distributing it uniformly up the building.

The figure of 1.1 for the minimum design force coefficient was chosen after discussion with the Building Ordnance Office so that the design shear force would not be less than that given by their interpretation of the HK wind code. However, using the results of the wind tunnel test, it was possible to justify the assumption of uniform pressure up the buildings so that in most cases the associated bending moments were reduced.

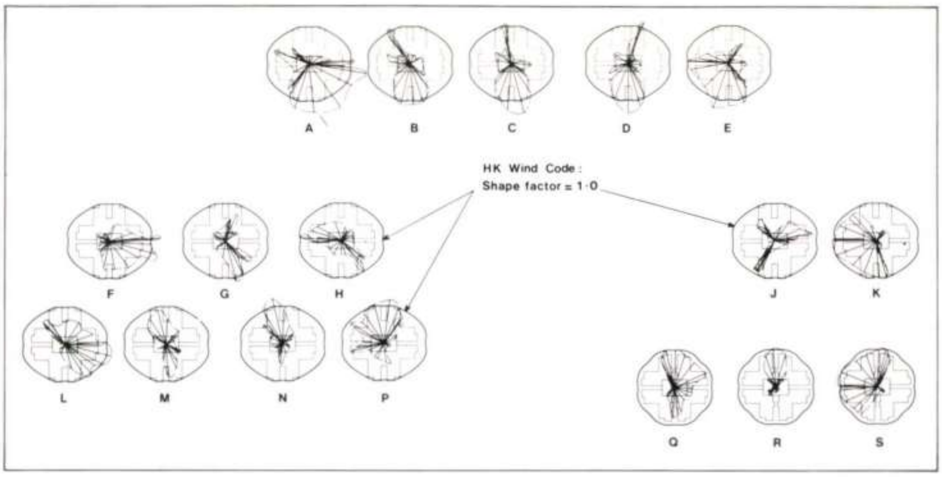


Fig. 13
Base shear forces – all blocks

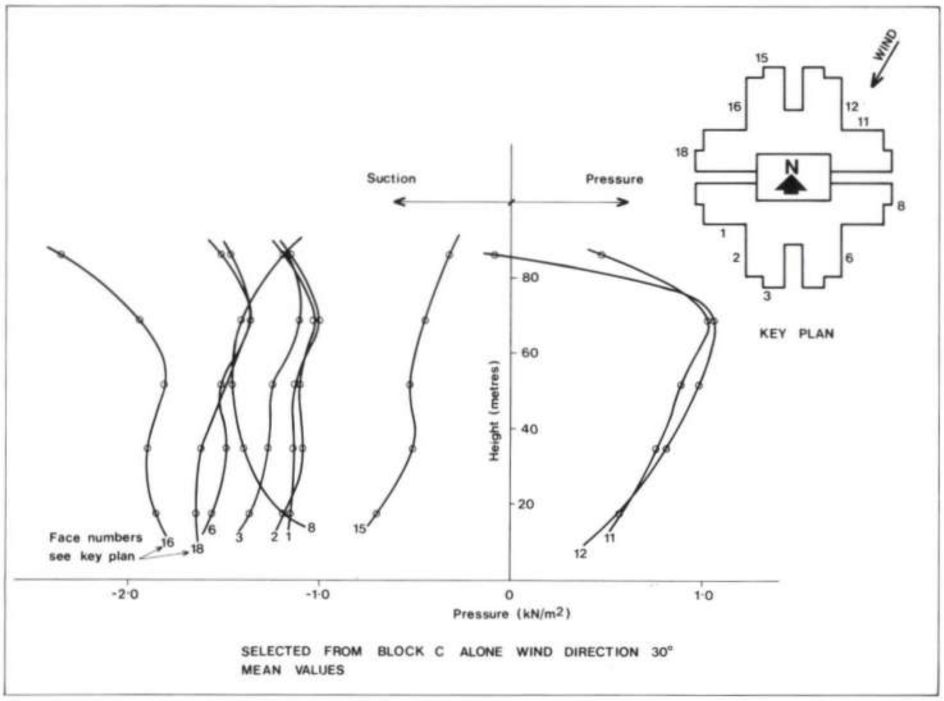


Fig. 14
Typical pressure distributions

Acknowledgements

The wind tunnel test was carried out under the direction of Mr Tom Lawson of the Department of Aeronautical Engineering at Bristol University and the computer analysis of the results was done by Bob Care.

Credits:

Architect:
Choa, Ko and Partners in association with Lee and Zee Associates

Client:
Mass Transit Railway Corporation of Hong Kong

Developer:
Luk Yeung Sun Chuen Joint Venture

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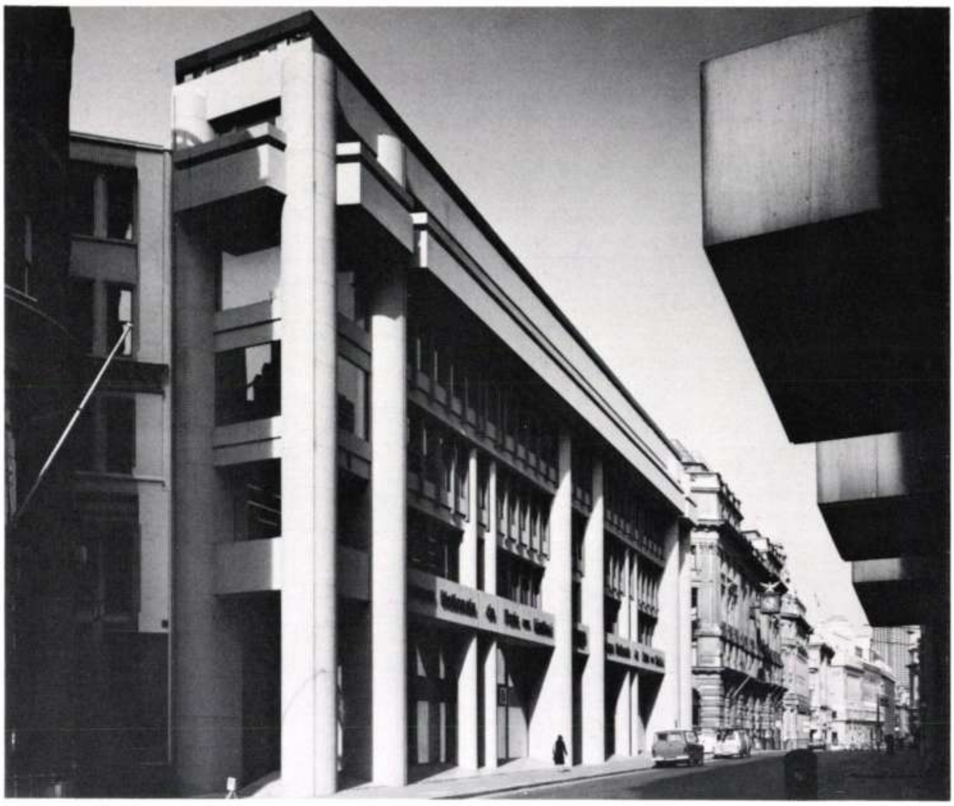
Civic Trust Awards 1979

Ove Arup & Partners have been involved with the following Award and Commendation winners shown here and on the back cover.



Award winners

Fig. 1 above
Job no. 5597 : Banque Nationale de Paris Ltd., 8-13 King William Street, London EC4.
Client: Banque Nationale de Paris Ltd.
Architect: Fitzroy Robinson & Partners
(Photo : Leighton Gibbins)

Fig. 2 left
Job no. 3893 : Bradford Transport Interchange
Client: West Yorkshire Passenger Transport Executive
Architects: Chief Architect, British Railways Board in association with Bradford City Architect
(Photo : Sam Lambert)

Fig. 3 below
Job no. 4473 : Wolverhampton Civic Centre
Client: Metropolitan Borough of Wolverhampton
Architect: Clifford Culpin & Partners
(Photo : Henk Snoek)

Civic Trust Awards 1979

(continued from previous page)

Commendation winners

Fig. 4 right
Job no. 3847 : Housing,
3-11 Lonsdale Place, London N1
Client: Barnsbury & Lonsdale Place Housing Association
Architect: Kenneth Pring & Associates
(Photo : Courtesy of the architects)

Fig. 5 below
Job no. 4860 : Housing,
Penton Street, London N1
Client: London Borough of Islington
Architect: John Melvin & Partners
(Photo : Courtesy of the architects)

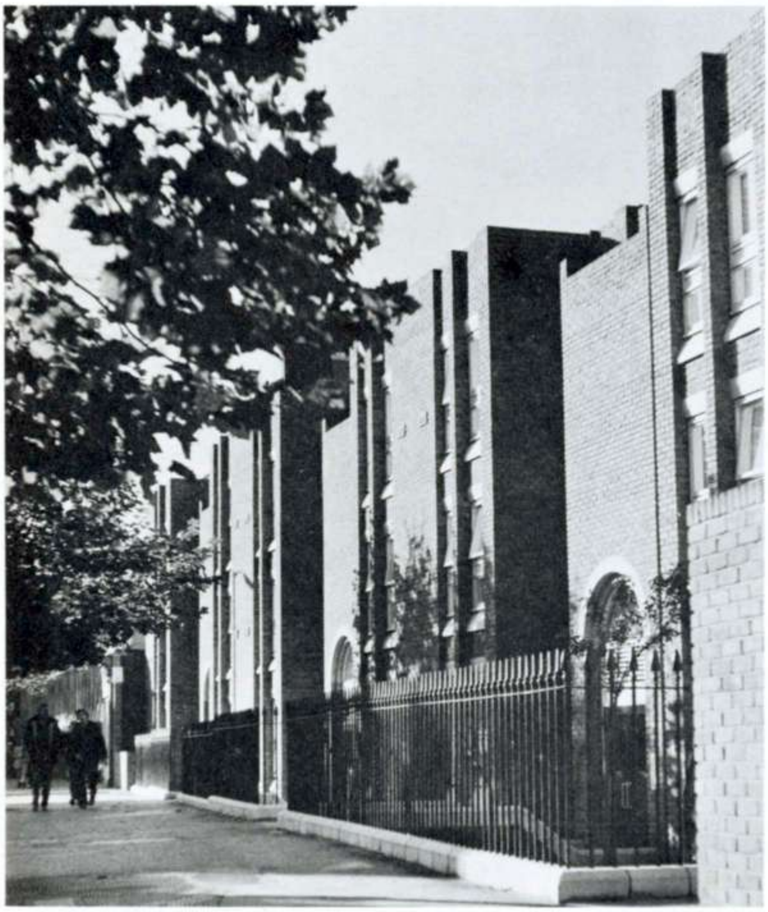


Fig. 6 above
Job no. 4345 : Lloyds Bank, Leeds
Client: Lloyds Bank Ltd.
Architect: Abbey & Hanson Rowe & Partners
(Photo : Abbey & Hanson Rowe & Partners)

Fig. 7 left
Job no. 3826 : Ecumenical Church & Chaplaincy, University of Manchester
Client: University of Manchester
Architect: Cruckshank & Seward
(Photo : Elsam, Mann & Cooper (Manchester) Ltd.)

Job no. 8210 : Great Western Terrace, Glasgow. Restoration (not illustrated)
Client: The Association of Great Western Terrace Proprietors
Architect: Stewart McPherson Associates

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