THE ARUP JOURNAL

JULY 1967

THE ARUP JOURNAL

Vol. 1. No. 5 July 1967 Published by
Ove Arup & Partners Consulting Engineers
Arup Associates Architects and Engineers
13 Fitzroy Street, London W1

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The front cover shows the north elevation of Scotstoun House from the car park entrance to the walled garden.
(Photo: Peter Foggo)
The back cover shows the east side of Scotstoun House showing the relationship between the existing garden wall and the building.
(Photo: Peter Foggo)

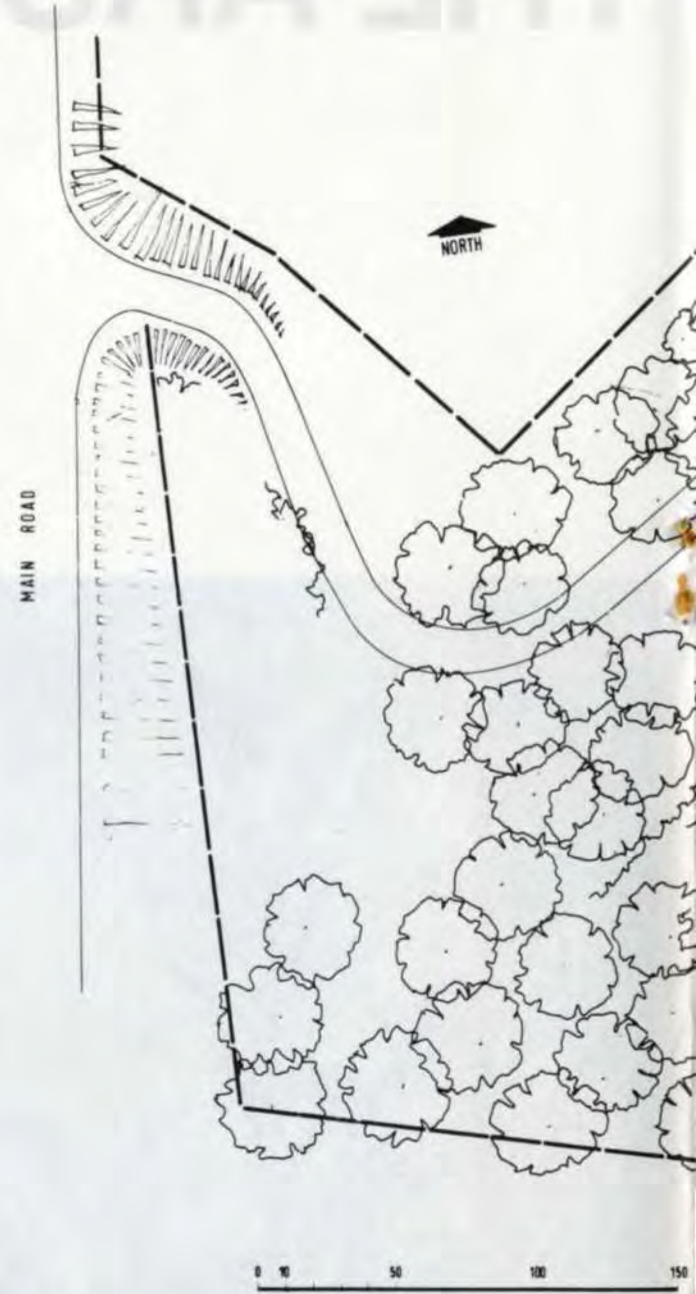


Fig. 1
Plan showing the house and grounds at Scotstoun before development

Scotstoun House

David Thomas

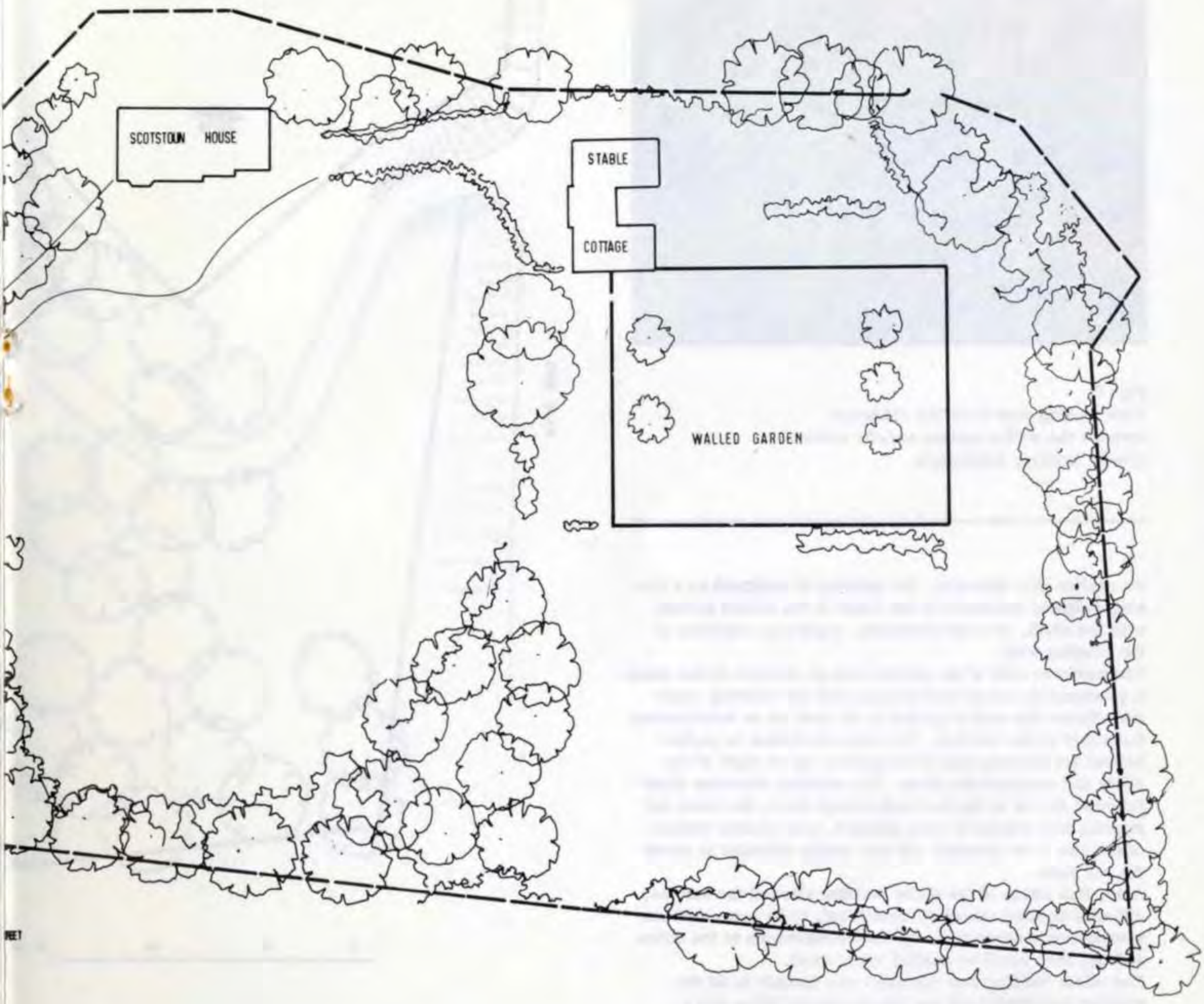
The Edinburgh office of Ove Arup & Partners Consulting Engineers was started early in 1960 by Tom Ridley to deal with the Ninewells Hospital Scheme at Dundee. By 1963 the office had grown sufficiently to warrant Fraser Anderson's joining Tom Ridley, and the 60 or so members of the staff occupied several small offices based around 90 George Street, Edinburgh.
The disadvantages of this fragmented set-up were as great in Edinburgh as those confronting the London office before the new offices in Fitzroy Street were acquired, and the partners decided, therefore, to build an office building to house all the Scottish staff.

THE SITE
After an extensive search in and around Edinburgh a site was found near South Queensferry - a town on the southern banks of the Firth of Forth, famous for the Forth Bridge and the recently completed road suspension bridge.

It is a small town about 5 miles from Edinburgh, and not far from Turnhouse Airport, with good road and rail access to all parts of Scotland.

The site, just south of the town and close to the approaches to the road bridge, was the site of a Georgian country house standing in about 6 acres of once carefully kept grounds, on the estate of Lord Primrose.

Apart from the house, which was in a badly neglected state, the equally neglected grounds contained a walled garden with adjoining stables and cottage. From the first it was obvious that this walled garden was the one feature of the site which together with the trees had to be retained and integrated with the design. The house could

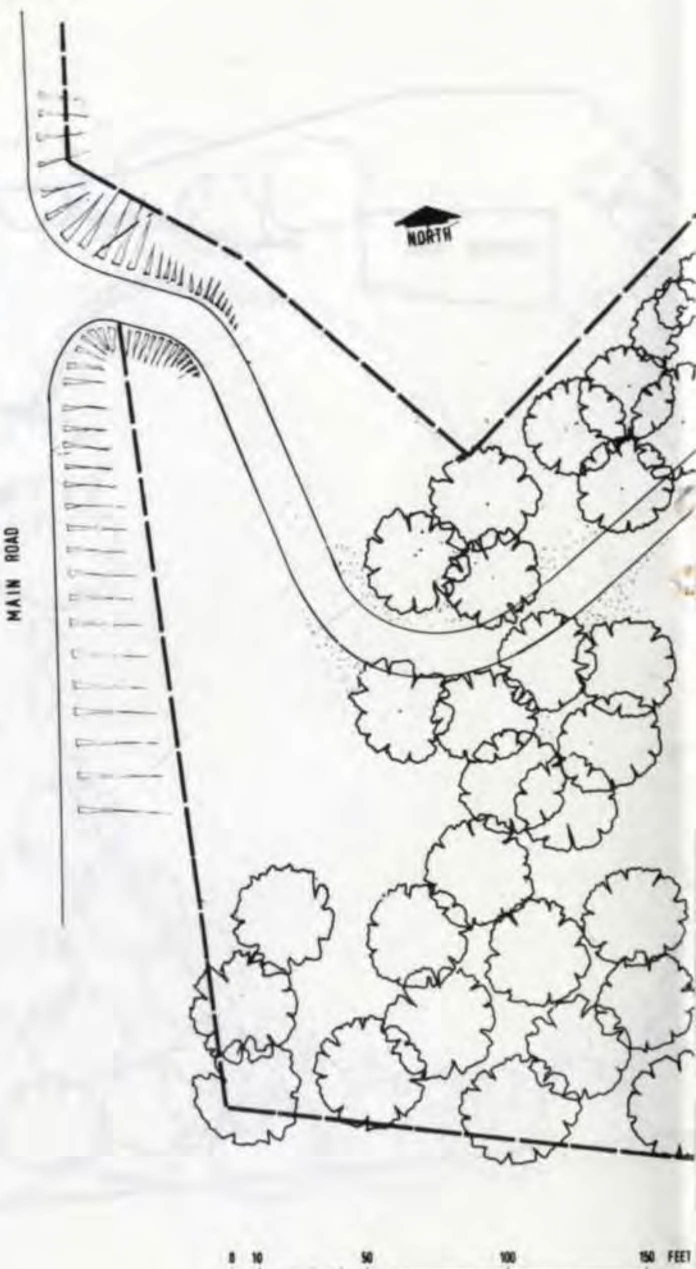


go, but the weather-beaten old walls, providing a sheltered area on a not so sheltered site, were a tremendous asset not to be ignored.

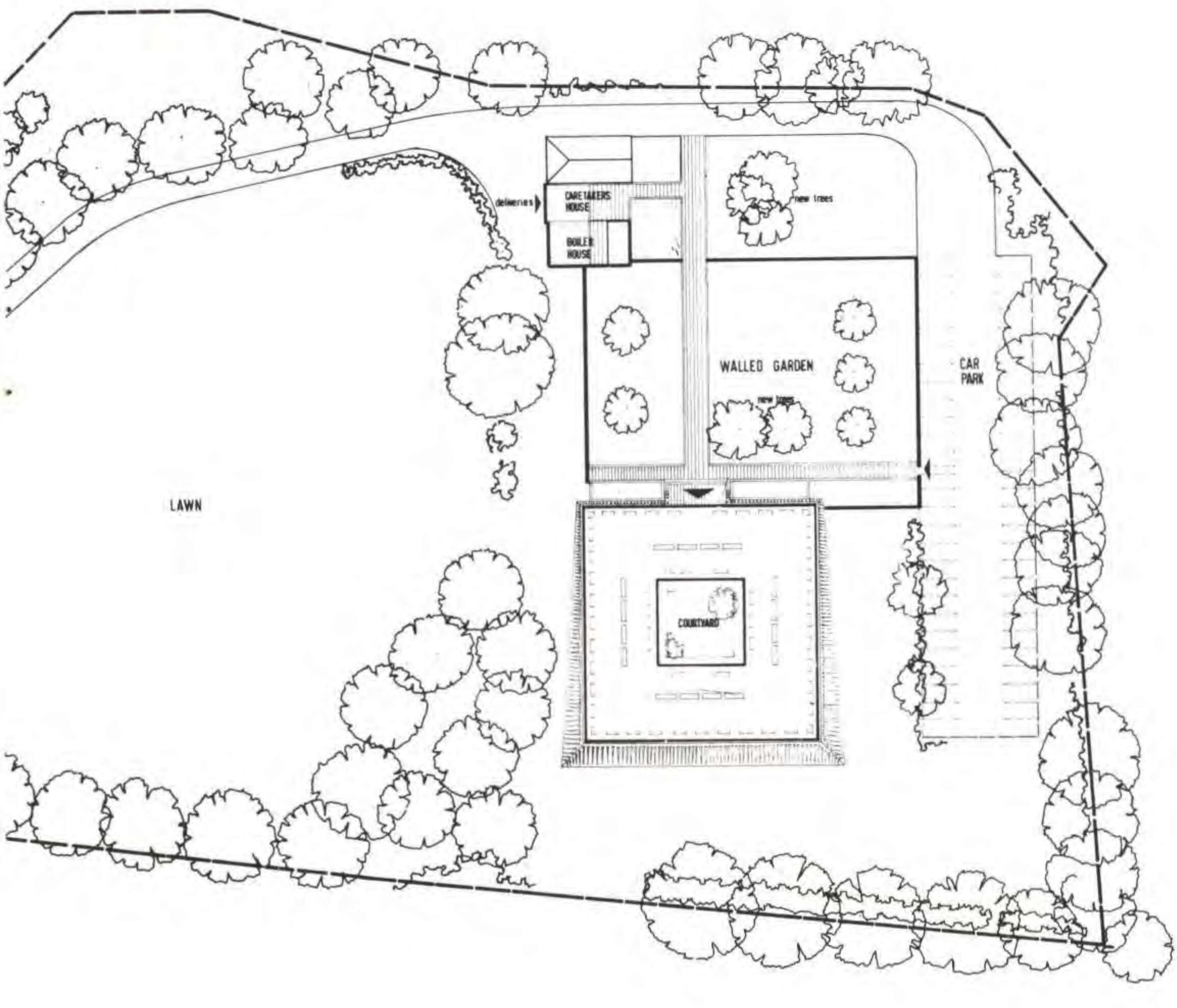
THE SET-UP
Two principal factors combined to make this project unique in our experience. One was, of course, the close relationship between the client, Ove Arup and Partners, and the consultants, Arup Associates.
This almost incestuous state of affairs might well have led to disastrous results, both to the goodwill between the two firms and to the building itself. In the event, however, it is fair to say that we have seldom, if ever, had such knowledgeable and co-operative clients as Tom Ridley and Fraser Anderson and, although they were sometimes cursed as clients sometimes are, there is no doubt that the speed of the project (15 months from briefing to occupation) and the resulting building benefited from their experience and enthusiasm.

THE DESIGN
The other unique factor was the notion of siting an office building in an essentially rural setting. This set a very real design problem in that it was clear that, above all else, the office building must not destroy the character of the setting. By its very nature, an office building could easily be antipathetic to fields and trees and, together with the car parking problem - made even more acute here by the lack of public transport - the whole project provided an exacting design exercise.
We felt that unobtrusiveness, and a sympathetic regard for the vernacular, were of the essence of the problem, and our subsequent decisions regarding the relationship between the building and the walled garden, the form of the building, the choice of materials and finishes, the retention of the stables as a converted caretaker's house, the use of the existing drive and our effort to hide the cars beyond the walls, were all influenced by this need to preserve the character of the surroundings.

Fig. 2
View looking east from the old house
towards the walled garden and the stables
(Photo: Norris, Edinburgh)

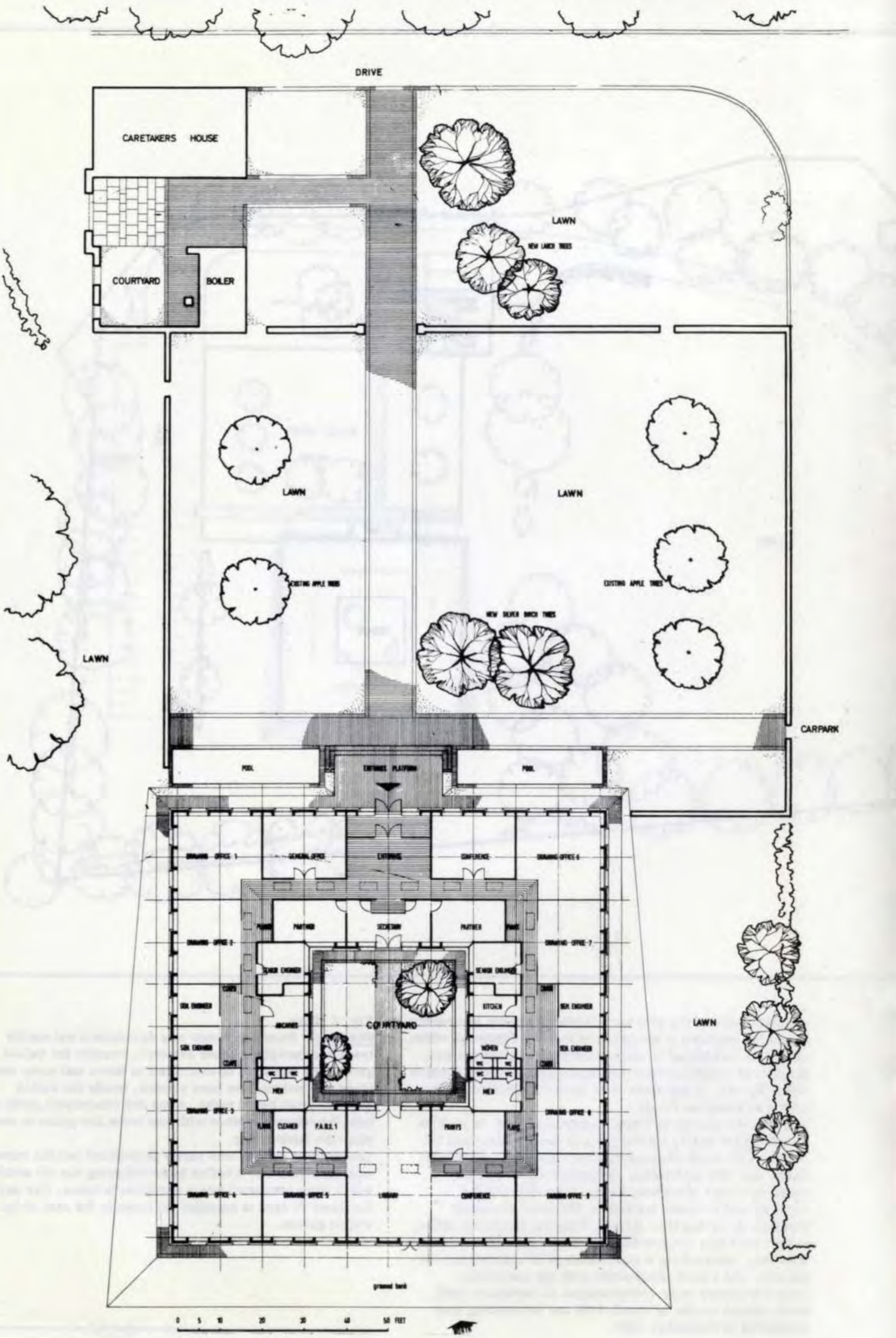


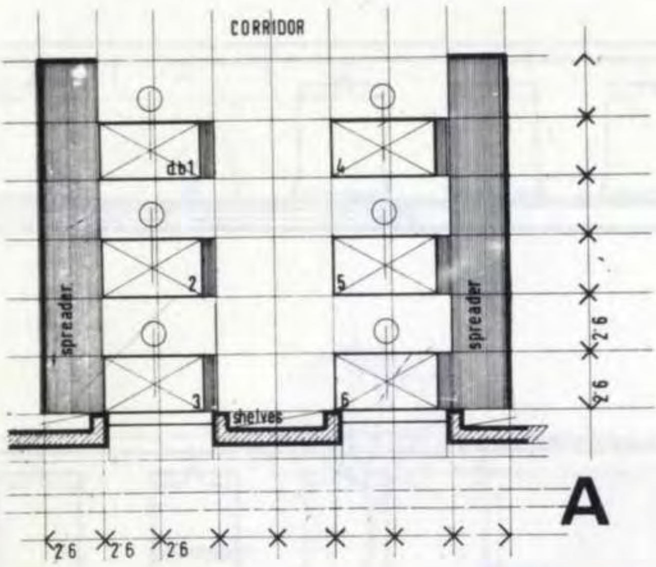
To realise this objective, the building is designed as a low single-storey structure to the south of the walled garden with the north, or front elevation, replacing a section of the existing wall.
The southern side of the garden was an obvious choice since it produced the least interference with the existing trees and allowed the walled garden to be used as an introductory forecourt to the building. The cars could then be parked beyond the eastern wall of the garden out of sight of the office and amongst the trees. The existing driveway which followed the lie of the land and around which the trees and planting had originally been planned, was another feature of the site to be retained and was easily extended to serve the car park.
Also, this siting of the office building allowed the stables, although needing extensive rebuilding, to be converted into a caretaker's house from where the entrances to the office and car park could be readily supervised.
The office building was designed on a module to fit the existing furniture from the George Street office and a certain degree of adaptability was required in the planning of the drawing office spaces. To achieve this, the six-man bays, considered to be the optimum initial grouping of staff, are divided by low screens which are re-arrangeable to allow different groupings should the need arise.
The core of the plan, the group of rooms surrounding and looking into the courtyard, was regarded as more or less permanent and the partitions, although non-loadbearing, are of double-skin timber construction with a cavity for services. Throughout the drawing office areas the heating and electrical services have been run around the perimeter of the building, leaving the floor space clear for rearrangement. The building is covered by a roof of timber joists, boarding and roofing felt, supported on steel universal beams spanning between precast concrete wall units. The roof overhangs the external wall, providing some cut-off from sky glare in an attempt to visually contain the view. The roof deck is surrounded by a steel channel edge member spanning between the main beams which, at the four outer corners, enables the roof deck to be cantilevered in two directions. The decision to maintain a regular spacing of the main beams, even at the entrance where the precast concrete supporting panel is omitted, was justified by the degree of standardization and the ease of construction achieved. The precast concrete units, which alternate with fixed glazing to form the external wall are U-shaped in plan and section to provide recesses for shelving and to give a deep reveal to the windows in an attempt to give the facade some modelling.
The traditional wall material in this part of West Lothian is either the local stone or rendered brickwork and we decided concrete would not be unsympathetic with these materials. The concrete was made from foam slag aggregate with an added dye to produce a tone similar to the tone of the stone garden walls. This material was chosen as an experiment, for its insulation value and its light weight, but the weathering properties, which were largely unknown, have proved disappointing.
The choice of precast concrete units, steelwork and dry materials for everything above slab level was further justified by the speed of construction achieved - $8\frac{1}{2}$ months from start to finish.
We were not asked to design a building allowing any major expansion in staff, but some leeway was required within



the framework of the plan for a limited increase in numbers. It was the intention of the partners that the Edinburgh office should be maintained at roughly the present numbers and, if future demands necessitated expansion, a second Scottish office in, say, Glasgow could be opened in preference to adding to Scotstoun House.
The contract was let to Wight Construction Ltd. of Falkirk on a fixed fee basis, the net costs of the job being met by Arups as the work proceeded. This method of contracting, which was very successful, demanded constant supervision by Arups of working hours, workmanship and ordering and checking materials. We were extremely fortunate in having Mike Brown, from the Edinburgh office, to take over this responsibility which he did with considerable skill, maintaining a good standard of workmanship on the site, and a good relationship with the contractor.
Arup Associates were commissioned in September 1965, work started on site in March 1966 and the building was completed by December 1966.

Fig. 3 above
Site Plan. Scotstoun House was demolished and unsafe trees and decaying bushes removed. Outside the walled garden the site is to be cultivated as lawns and many new trees and hedges have been planted. Inside the walled garden, brick paved paths, steps and ornamental pools have been introduced together with new trees and grass to complete the landscaping.
The existing cottage was partly demolished and the remainder was converted into a boiler house adjoining the old stables which were converted into a caretaker's house. Car parking for some 40 cars is amongst the trees to the east of the walled garden.


DRIVE
CARETAKERS HOUSE
COURTYARD
BOILER
LAWN
NEW LARCH TREES
LAWN
LAWN
EXISTING APPLE TREES
NEW SILVER BIRCH TREES
EXISTING APPLE TREES
LAWN
CARPARK
POOL
ENTRANCE PLATFORM
POOL
ENTRANCE
GENERAL OFFICE
CONFERENCE
SECRETARY
PARTNER
PARTNER
COURTYARD
LIBRARY
CONFERENCE
grassed bank
LAWN
0 5 10 20 30 40 50 FEET



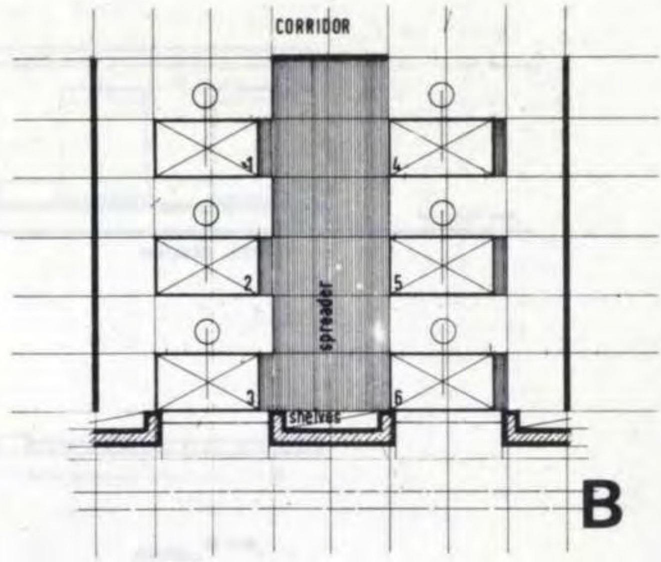


Fig. 4 Left, on facing page
Office Plan. The main drawing office spaces face east and west with immediate views of lawns and trees. The smaller offices face into the courtyard. White painted removable partitions between the drawing offices allow variations of the six men grouping. The permanent core partitions are stud framed and faced both sides with British Columbian edge-grained tongued and grooved boarding. The ceiling throughout is again British Columbian pine boarding and the floor finish is a dark green linoleum.

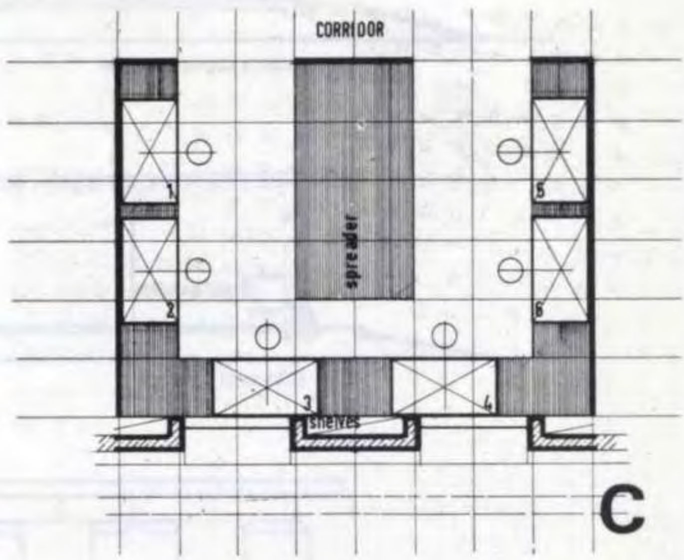


Fig. 5 A, B and C above and right
Possible layouts of the six men drawing office bay. Layout A was chosen as the layout for all the bays.

Fig. 6 below
One of the 7-men corner drawing offices.
(Photo: Reg Rigby)

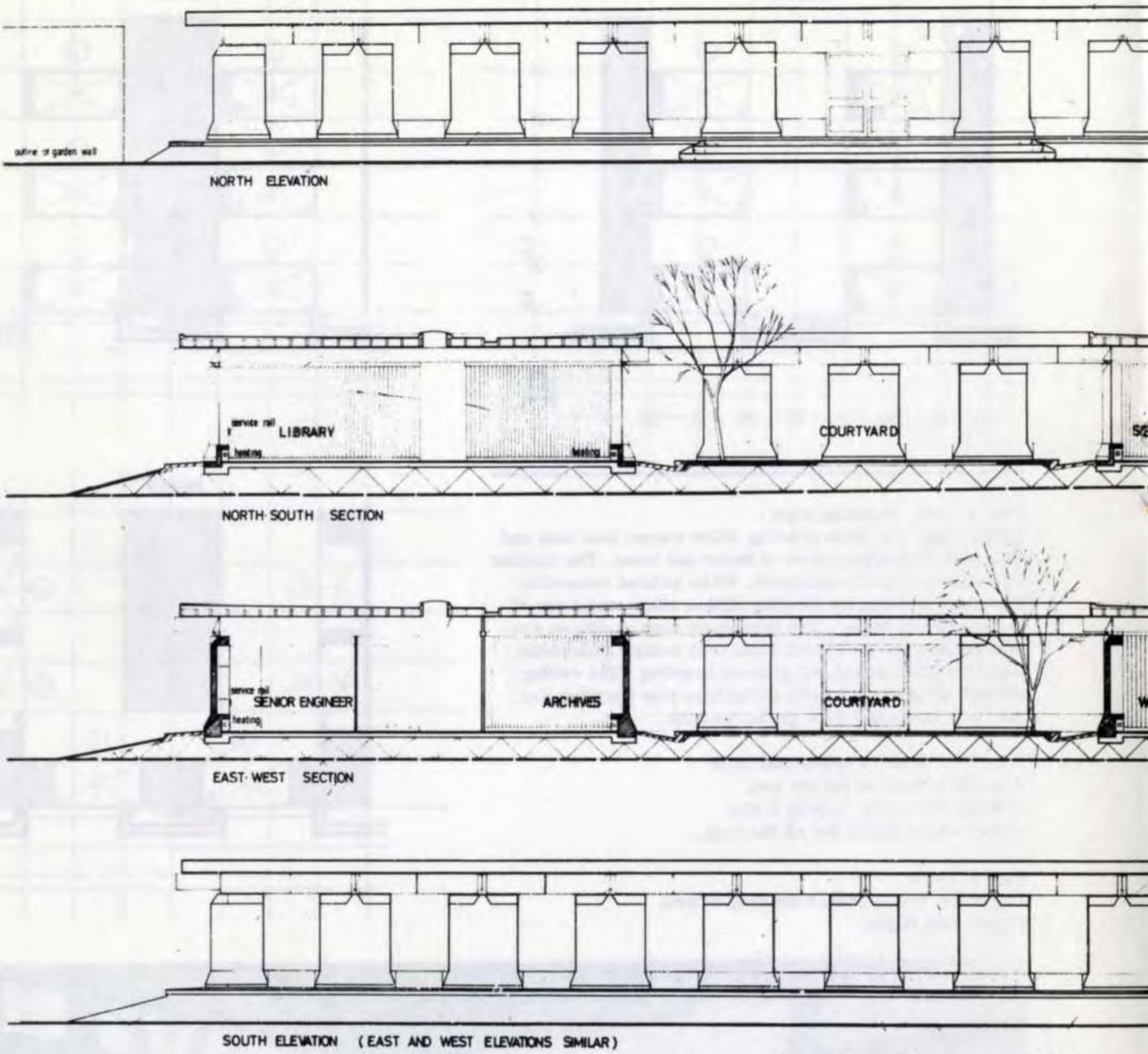


Fig. 8 below
The south elevation. (Photo: Reg Rigby)

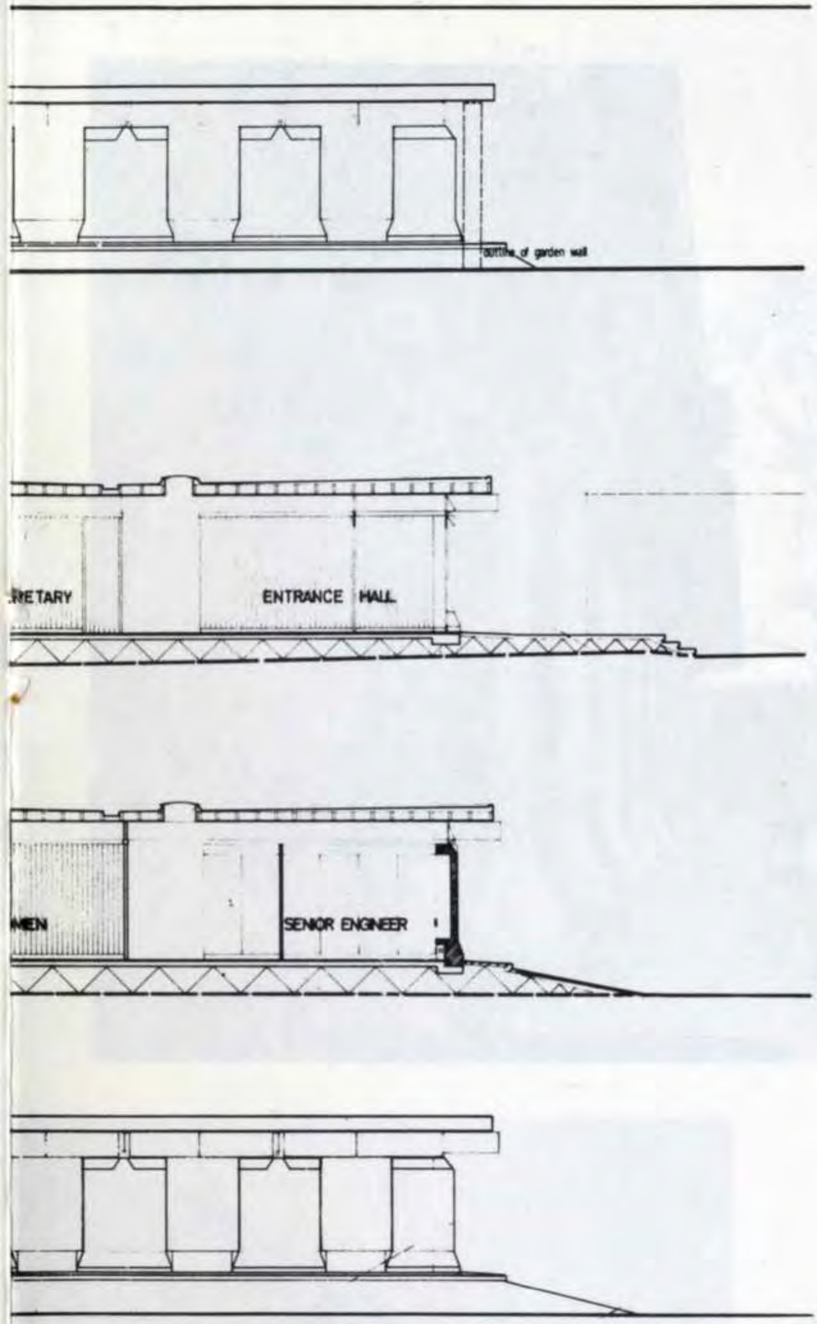


Fig. 7 left

Elevations and sections. The concrete panels are dark grey in colour and the steelwork both internally and externally was shot blasted, primed and painted with a dark brown micaceous iron oxide paint. The concrete panels alternate with areas of fixed glazing and top hung ventilators at high level between the beams give natural ventilation around the entire perimeter of the building. The main beams downstand below the roof deck and span 33 ft. The head of the full height core partitions is detailed with a sliding joint to allow for deflection in the steelwork.

Socket outlets and telephone points are housed in a service rail at desk-top height around the perimeter of the building. Heating is by gill tubes housed in the sill units.

Fig. 10 above

A corner of the internal courtyard. (Photo: Reg Rigby)

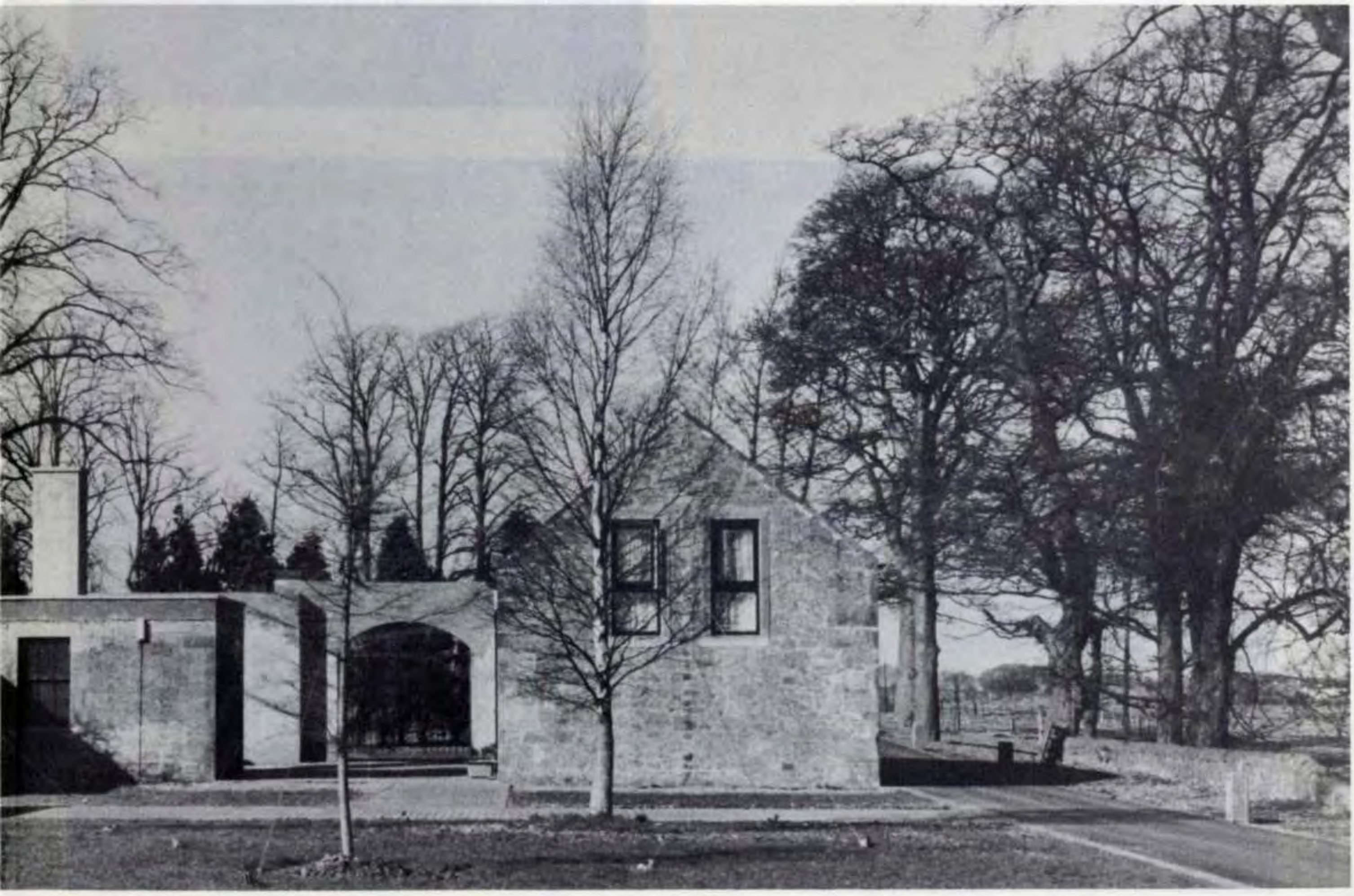
Fig. 9 below

The building from the south west. (Photo: Peter Foggo)

Fig. 11 above
The south west corner
of the walled garden showing the relationship
between the building and the walls
(Photo: Reg Rigby)

Fig. 12 right
The ground floor slab is built on a low plinth which provides
a level platform on the slightly sloping site and which raises
the ground floor level sufficiently to allow a short flight of
steps to mark the entrance.
(Photo: Reg Rigby)

Fig. 13 top right
The caretaker's house and boiler house.
The arched gateway in the background was
formerly the entrance to the coach house.
(Photo: Peter Foggo)



Bush and pick-hammered concrete on the Barbican scheme

J. A. Waller

Exposed in situ concrete has been used on many jobs. Some have been notably successful. Some have been awful failures, and it is clear by now that the successful use of structural concrete as an exposed self-finished material is a complex and expensive operation requiring great care in both design and execution.
There are two types of finish, that which is left 'as struck' and that which is treated in some way, usually tooling, after the shutters have been removed. An example of the former is the G.L.C. South Bank Development (1). This article is concerned with an example of the latter.
On the Barbican Redevelopment Scheme structural concrete is exposed on the faces of the buildings and in lobbies, stairways and car parks. Much of this exposed work is either bush-or pick-hammered. On the three £6 million contracts currently under construction something over a quarter of a million square yards of concrete surface will eventually be tooled.

THE SPECIFICATION
The specification (2) required the shuttering to be to an approved regular pattern and severely restricted the use of fixing bolts through the concrete. Irregularities and blemishes were also limited to tight tolerances. For pick-hammering the contractor was required to pit the surface of the concrete in an irregular pattern to an average depth of $\frac{1}{2}$ in. but not more than $\frac{3}{4}$ in. using a pick or chisel bit (Figs. 1 and 2). For bush-hammering the surface of the concrete was to be evenly removed to a depth not greater than $\frac{1}{4}$ in. using a cruciform bit (Figs. 3, 4, 5 and 6). Pin-hammering, a very light type of bush-hammering, was also specified, but it has not been used. The concrete was not to be less than 21 days old when tooled.
Retarders were not permitted as these did not give the type of finish required by the architects, Messrs. Chamberlin, Powell & Bon.

Fig. 2
Block 12.
Pick-hammered column

Fig. 1
Block 11.
Pick-hammered edge beam

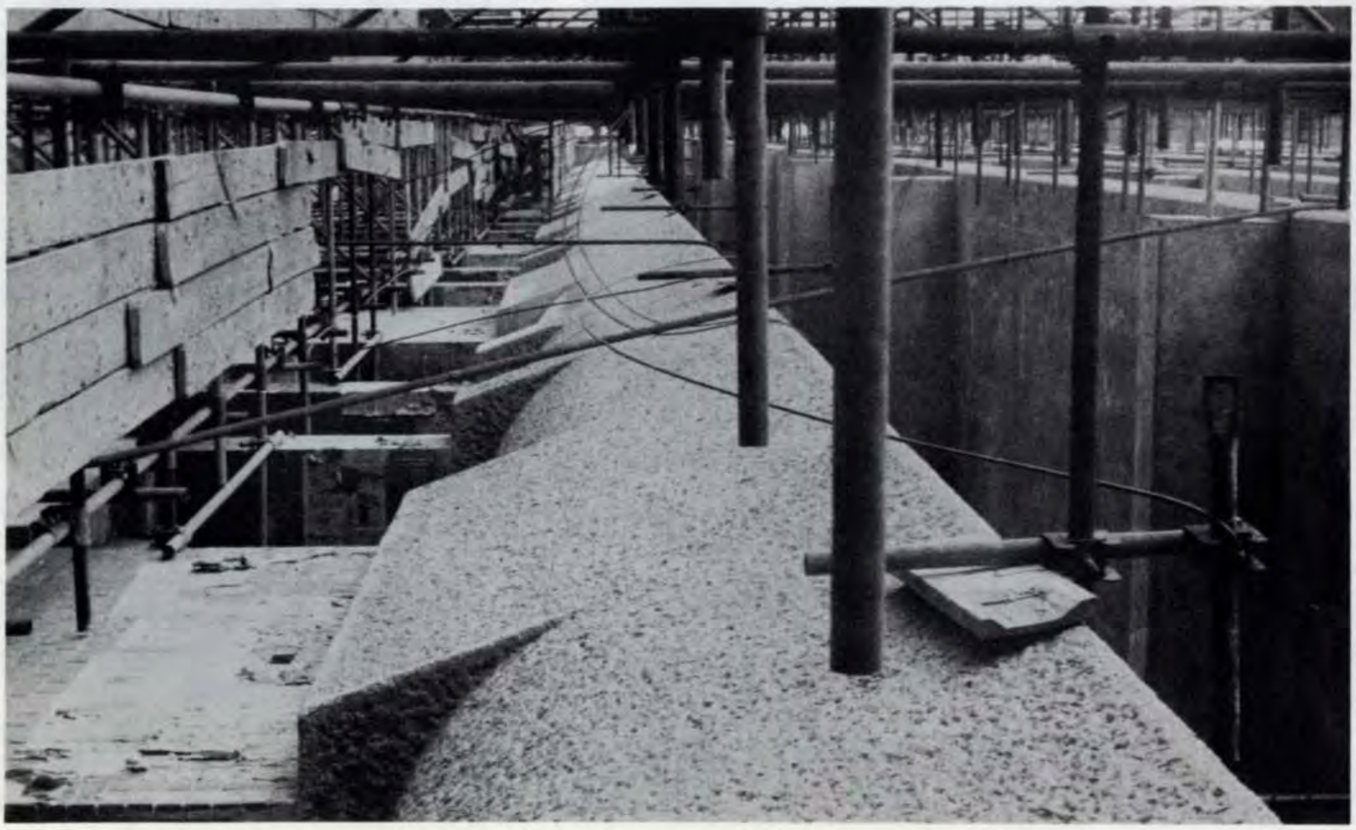


Fig. 3 above
Tower Block 1.
Lobby walls after bush-hammering;
shuttering joints still show.

Fig. 4 below
Tower Block 1.
Staircase wall after bush-hammering;
shutter joints and bolt holes still show

Fig. 5 above
Block 11.
Typical mark left by shutter joint
after bush-hammering

SHUTTERING

The biggest single factor in achieving good quality tooled concrete surfaces is the shuttering. Every joint in the shuttering will show through the finished treatment as tooling does not mask the joints. Even a joint between two sheets of ply within one shutter panel will tend to show as a dark line (Figs. 3, 4, 5 and 6). It is therefore essential that the shutter panels should be set out to a predetermined pattern which takes into account the features of the building. It is desirable to introduce a feature, such as a recess, along the horizontal joints. This masks any slight irregularities and helps to conceal the fact that generally the concrete is a slightly different colour above and below a joint (Fig. 7). At Barbican there were only a few places where this device could be used. The actual quality of surface finish is not critical, although in the case of bush-hammered work similar absorbency is necessary to maintain constant colour. The real key to success is simply the fact that the shutters must be absolutely watertight. This is easier said than done! Where shutters have to be clamped against existing concrete, grout loss will produce a 'hungry' joint which will often look worse after tooling than it did before. Polyurethane foam and various rubber seals (e.g. TRETOL 1 in. x 1 in. neoprene rubber foam) have been used successfully providing the seal is firmly secured to the shutter and tightly clamped to the existing work. These remarks apply equally to joints between one shutter panel and another and again it is essential that the joint is clamped up tightly. Nailing is insufficient, bolts at close centres are essential.

The edges of the sheets of ply must also be sealed, otherwise the moisture absorbed by the cut edge is sufficient to cause a dark line to appear. Fair success has been achieved by filling the joint with glue and varnishing over it. One thing is certain, a cover strip at the rear of a timber shutter is not sufficient.

Shuttering ply can now be obtained in very large panels consisting of standard sheets scarf-jointed together and these have been used with considerable success on the Barbican.

An alternative technique which was tried was to stick pvc tape over the joint on the inside of the shutter. This was successful provided the shutter was absolutely free of mould oil, otherwise the tape crinkled and became embedded in the concrete. On steel shutters tape stuck on the outside of the joint was not very successful,

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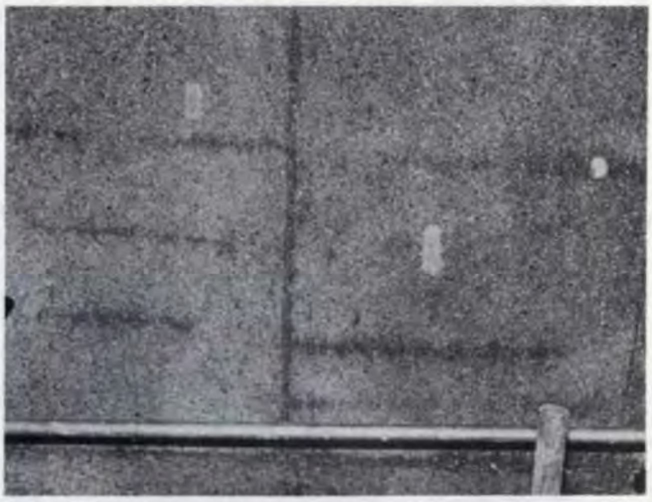

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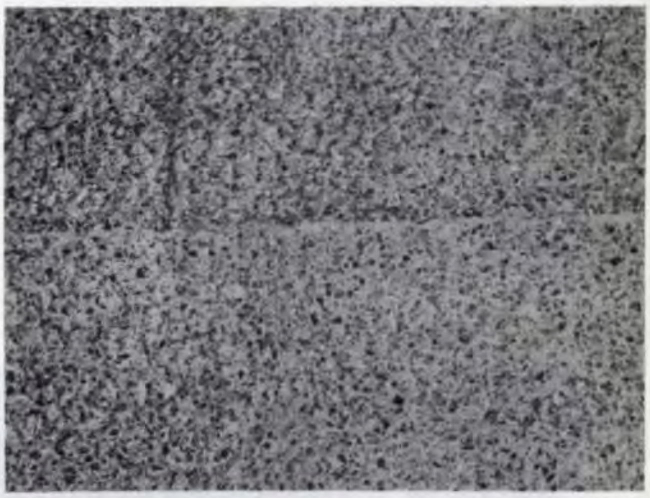

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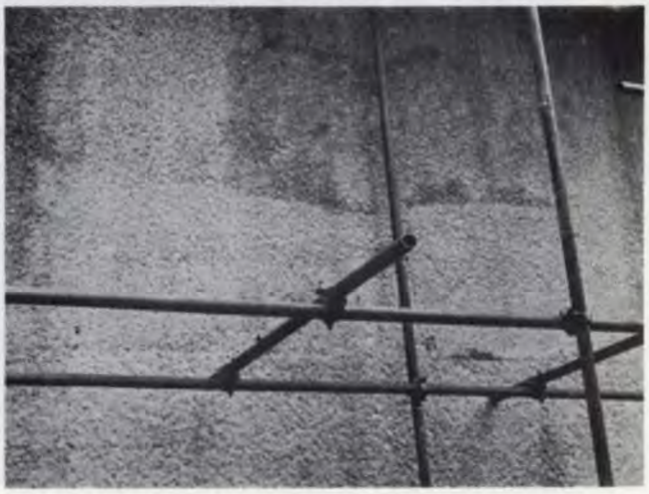


Fig. 6
Block 6.
Slab soffit, shutter joints and fixing blocks still showing after bush-hammering

Fig. 7
Block 8.
Colour change at horizontal joint in pick-hammered cross-wall.
Vertical shutter joints also visible

Fig. 8
Block 6.
Laitance shows as white line at horizontal construction joint

Fig. 9
Block 8.
Concrete allowed to harden during pour; emphasized by pick-hammering

apparently the moisture lost into the gap between the shutter flanges was enough to leave a mark in the concrete.
As a general rule it is worth remembering that every joint is likely to continue to show after tooling, surface blemishes are more likely to get worse than better with tooling, and if a surface has bulged and has to be trimmed back to line that also is likely to show differently, particularly with gravel aggregate.

BOLT HOLES

Some bolt holes are usually inevitable and obviously they should be positioned to a regular pattern. The smaller the bolt hole left the easier it is to conceal it and WILLIAMSFORM bolts which leave about $\frac{3}{4}$ in. diameter holes have been quite successful. The holes are plugged with a special 'making good' mortar (see below) with a few small pieces of aggregate pushed in at the end to mingle with the tooled surface. Great care has to be taken as these holes could be a weak point where a wall is exposed to the weather on one side. A rubber or plastic bung might be a better way of doing it, but some development work is required.
With use the bolt holes in the shutters become worn and permit moisture to escape. The introduction of a steel plate helps to prevent this, so does a rubber seal which is a push fit on the bolt at the back of the shutter.

COVER

This is a very important consideration. Not only is part of the cover removed but some of what remains after tooling is shattered. Further experiments are needed to establish the depth of this shattered zone. We considered that shattering was unlikely to go deeper than one piece of aggregate, namely $\frac{3}{4}$ in. and we finally assumed $\frac{1}{2}$ in. average depth over and above the normal cover. For picked surfaces, we therefore added an extra $1\frac{1}{4}$ in. ($\frac{3}{4}$ in. removed + $\frac{1}{2}$ in. shattered). Since, despite the specification, some of the pits cut are in fact an inch deep, this allowance does not seem to be over-generous. As might be expected a point bit cuts deeper than a chisel bit.
For bushed surfaces we allowed $\frac{3}{4}$ in. extra cover ($\frac{1}{4}$ in. removed + $\frac{1}{2}$ in. shattered). In fact $\frac{1}{2}$ in. would probably have been sufficient, but the extra has been very useful in allowing local bulges to be cut back without reducing the effective cover.
Cover is generally achieved with conventional spacer blocks but it has been found that the blocks have to be made from the standard mix from the mixing plant and not from something 'knocked up' in the usual manner. Even so some show up on bushed soffits (Fig. 6).
In the walls, withdrawable timber battens have been used but they can be unsatisfactory as the vibrators can move the steel after the battens are withdrawn.

MIX

We have found that this needs to be kept reasonably consistent to provide consistent appearance, but cement/aggregate ratios varying 1:4.5 to 1:6 have not significantly affected the appearance.
The water content needs to be kept to a minimum. Excess tends to rise to the top of the pour and give a layer of laitance which shows as a light line at the construction joint (Fig. 8). This can be scabbled off but then the line of the joint becomes ragged in appearance. A plasticizer helps considerably in overcoming this problem.
The coarse aggregate originally specified for exposed work was HITHERMOOR crushed flint gravel. Unfortunately the attractive blues and blacks in tooled gravel concrete oxidize to an indifferent gingery colour. This can be seen in the Public Services Building - the first building completed. All subsequent exposed face work has been in PENLEE crushed granite from Newlyn. This is shipped to London by Amalgamated Roadstone Co. primarily for use as roadstone, and consequently the grading for concrete purposes leaves something to be desired. Fine aggregate is SANDOE zone 2 Sand from the British Dredging Co. The standard mixes have 4800 psi and 6000 psi nominal 28-day strengths.
One advantage that granite has over gravel is that if bulges have to be cut back granite keeps its colour fairly well but gravel shows a distinct colour change when shattered by deep cutting.

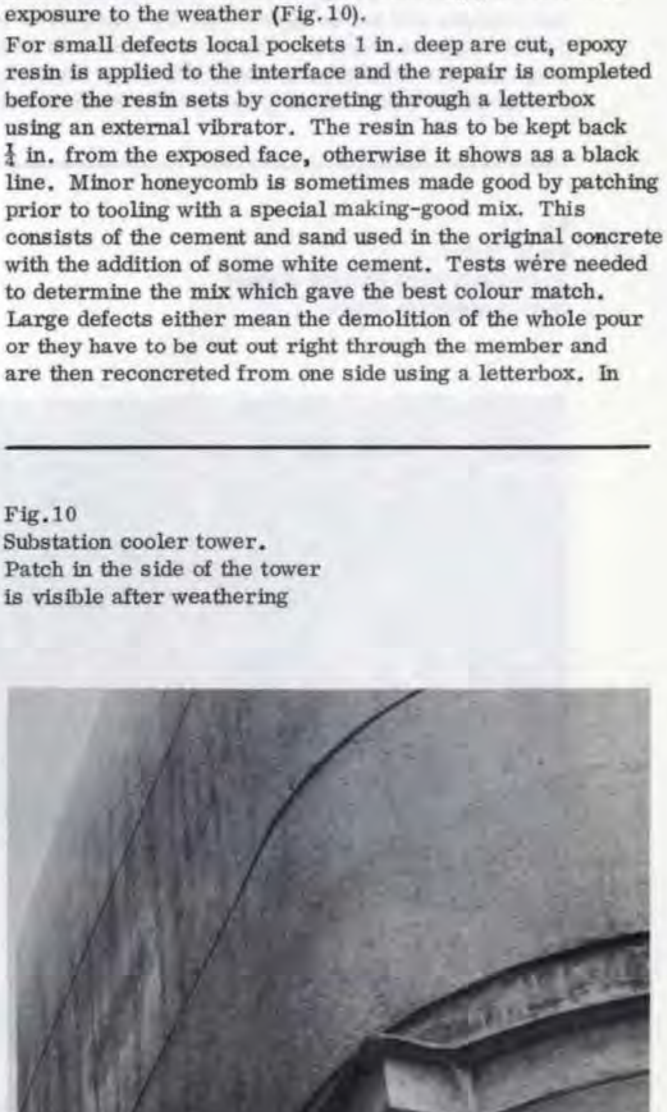
COLOUR

In general the colour of the tooled concrete on the Barbican site is fairly consistent but it has proved impossible so far to control it with any certainty and on occasions concrete appreciably darker or lighter than the average is produced (Fig. 7). All materials are drawn consistently from the same sources. The cement comes from only one factory. Experiments are in hand to try to establish the causes of colour variation and to find means of toning darker or lighter pours to bring them to a better match. It seems probable that the cement is the principal cause of variation and to improve the situation would mean finding a factory with a smaller variation. A further complication arises in that the colour of a pour varies from top to bottom, the bottom being denser than the top. To some extent this factor is obviously dependent on the height of pour (up to 40 ft. has been used on Barbican) but the parameters have not been established.
If the concrete is allowed to go off during pouring, other unpleasant patterns may be discovered later! (Fig. 9)

MAKING GOOD

If a defect is sufficiently bad to require repair then consideration has to be given as to whether a patched area can be accepted or whether the situation is such as to warrant removal of the whole pour. A patch which is almost invisible when new may be startlingly visible after exposure to the weather (Fig. 10).
For small defects local pockets 1 in. deep are cut, epoxy resin is applied to the interface and the repair is completed before the resin sets by concreting through a letterbox using an external vibrator. The resin has to be kept back $\frac{1}{4}$ in. from the exposed face, otherwise it shows as a black line. Minor honeycomb is sometimes made good by patching prior to tooling with a special making-good mix. This consists of the cement and sand used in the original concrete with the addition of some white cement. Tests wére needed to determine the mix which gave the best colour match. Large defects either mean the demolition of the whole pour or they have to be cut out right through the member and are then reconcreted from one side using a letterbox. In

Fig. 10
Substation cooler tower.
Patch in the side of the tower
is visible after weathering



order to make the patch as inconspicuous as possible in a tooled face the hole is cut to a neat clean edge with hammer and chisel. The slight irregularity of such an edge mingles better with a tooled finish than one produced by a concrete saw. The saw however produces a better edge for fair-face work.

Amongst repairs carried out have been some to several of the 40 ft. high 4 ft. diameter pick-hammered columns. These columns are split by a service entry at the bottom. They were poured in one go to avoid joints but when stripped some of the first ones were badly honeycombed at the bottom beside the service entry. At this level the concrete will eventually be stressed to 2500 psi average and about 1/6th of the plan area had to be cut away and reconcreted. This was done by cutting a cavity with an inclined upper surface to release the air and then applying epoxy resin to the cut faces immediately before reconcreting through a letterbox. Before this method of repair was attempted tests were carried out on standard cylinders which were cut and joined in the proposed manner and tested to failure.

The repair has merged well and is now scarcely visible despite the fact that the external line was cut with a carborundum disc contrary to the advice given above.

On another occasion an 18 in. wall was refaced by cutting off a 6 in. skin and reconcreting it from the top using poker vibrators. In this case epoxy resin was not used.

As a general rule patches are always taken well behind the first layer of steel and repairs to pick-hammered work are never less than 4 in. deep for fear that the pick-hammering might dislodge the repair.

One important point to be borne in mind when considering whether or not to permit repairs to be attempted is that the final results will not be known until the concrete is tooled. By this time the structure may have advanced to such a stage that the demolition is very difficult or even impossible. It is probably better in many cases to be swift and brutal and demolish the offending work and not trust to patching which at best is an uncertain art!

Rust stains from exposed bars above and from scaffold connectors are a continuing problem (Fig. 11). Reasonably satisfactory results have been obtained by scrubbing stains with a bristle brush and weak acetic acid, but if a stain has got well into a picked surface it is practically impossible to get it all out. Ideally, tooling should be left until the work above is advanced sufficiently to prevent contamination.

Fig. 11
Girls' School.
Bush-hammered surface stained from scaffolding above

AGE AT WHICH TOOLING IS CARRIED OUT

After some experiments we decided that concrete could be bush-hammered when it reached its 28-day strength, this is usually about 10 days after casting. But with pick-hammering it was found that the tools cut too deeply at this age and we have kept to the specified minimum age of 21 days.

RATE OF WORKING

Test panels showed that the rate of tooling on gravel was approximately twice as fast as on granite. The test panels were divided into sections each one half of a square yard and the following results were obtained:[3]

Pick-hammering	Time for a $\frac{1}{2}$ sq. yd. panel	
Point bit	Granite	Gravel
25-day concrete	32 mins.	17 mins.
35-day concrete	28 mins.	12 mins.
Chisel bit		
25-day concrete	37 mins.	18 mins.
35-day concrete	26 mins.	17 mins.
Bush hammering		
Cruciform bit on triple scaling tool		
35 days	13 mins.	7 mins.

Pick-hammering was done with an air-driven hammer - a CP9 from Consolidated Pneumatic Tool Co. Ltd. The point bit was a PEG POINT. The chisel was 1 in. wide (Fig. 12). Both were from C.P.T. Co. Ltd.

Bush-hammering was done with a Holman No. 5 triple scaling tool (Fig. 13).

In some of the subsequent work bush-hammering was also done with a CP9 and a single cruciform bit (Fig. 14).

COSTS

When we have collected sufficient information about the cost we will publish it.

POSTSCRIPT

It is possible to get a jointless bush-hammered surface. A notable example is the conference hall under the Pirelli Building, Milan. This was achieved by applying a two-coat render to the structure, the top coat containing a 3/8 in. coarse aggregate. The render was then bush-hammered! This type of finish is available in this country at a cost of the order of 75/- per sq. yd.

ACKNOWLEDGEMENTS

I should like to acknowledge the help given by Mike Conacher and Jim Dallaway.

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(1) POWELL, A.C. Rough concrete on site. The Arup Journal, pp. 7-12, July 1966.

(2) Barbican Redevelopment Scheme (Job no. 1023) Phase 2 Contract documents, Bill no. 1.

(3) OVE ARUP & PARTNERS. Barbican Redevelopment Scheme (Job no. 1023). Report on the results of the pick and bush-hammering finish tests carried out ... A. Stevens, November 1965.

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14

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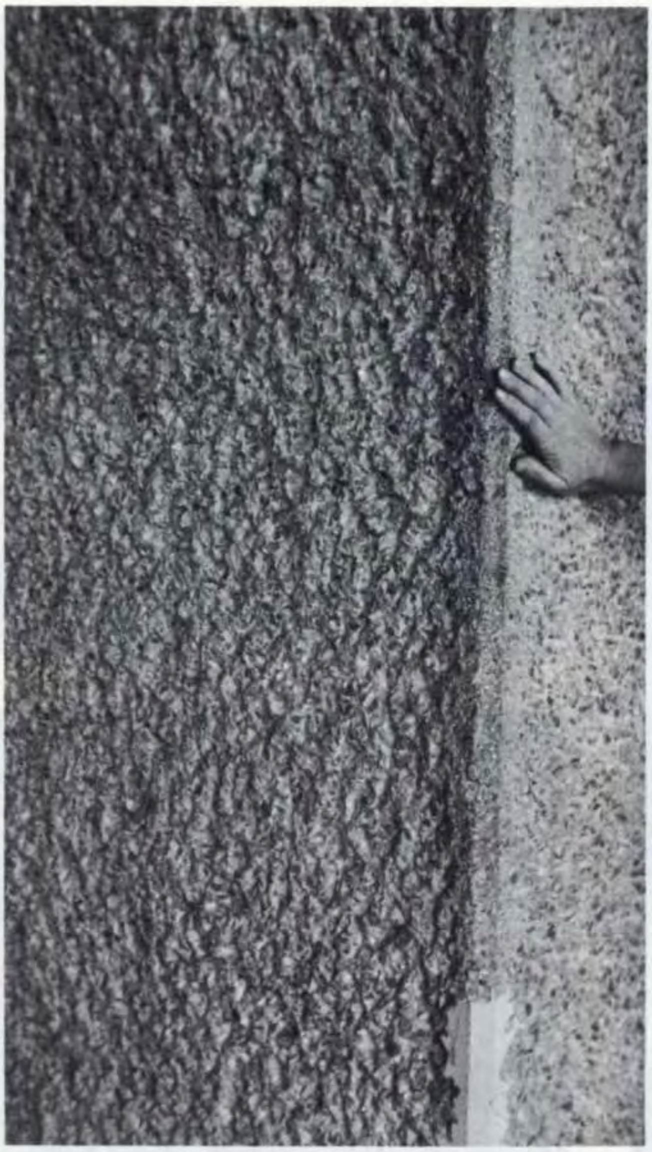
Fig.12
Block 6.
Pick-hammering with a chisel bit

Fig.13
Block 6.
Triple scaling tool for bush-hammering

Fig.14
Multiple cruciform bit also used
for bush-hammering.
(Note, this tool was not used
for the work in the background
which is pick-hammered)

Fig.15
Block 11.
Expansion joint in a split column;
difficulty in keeping a clean edge
in pick-hammered work

16



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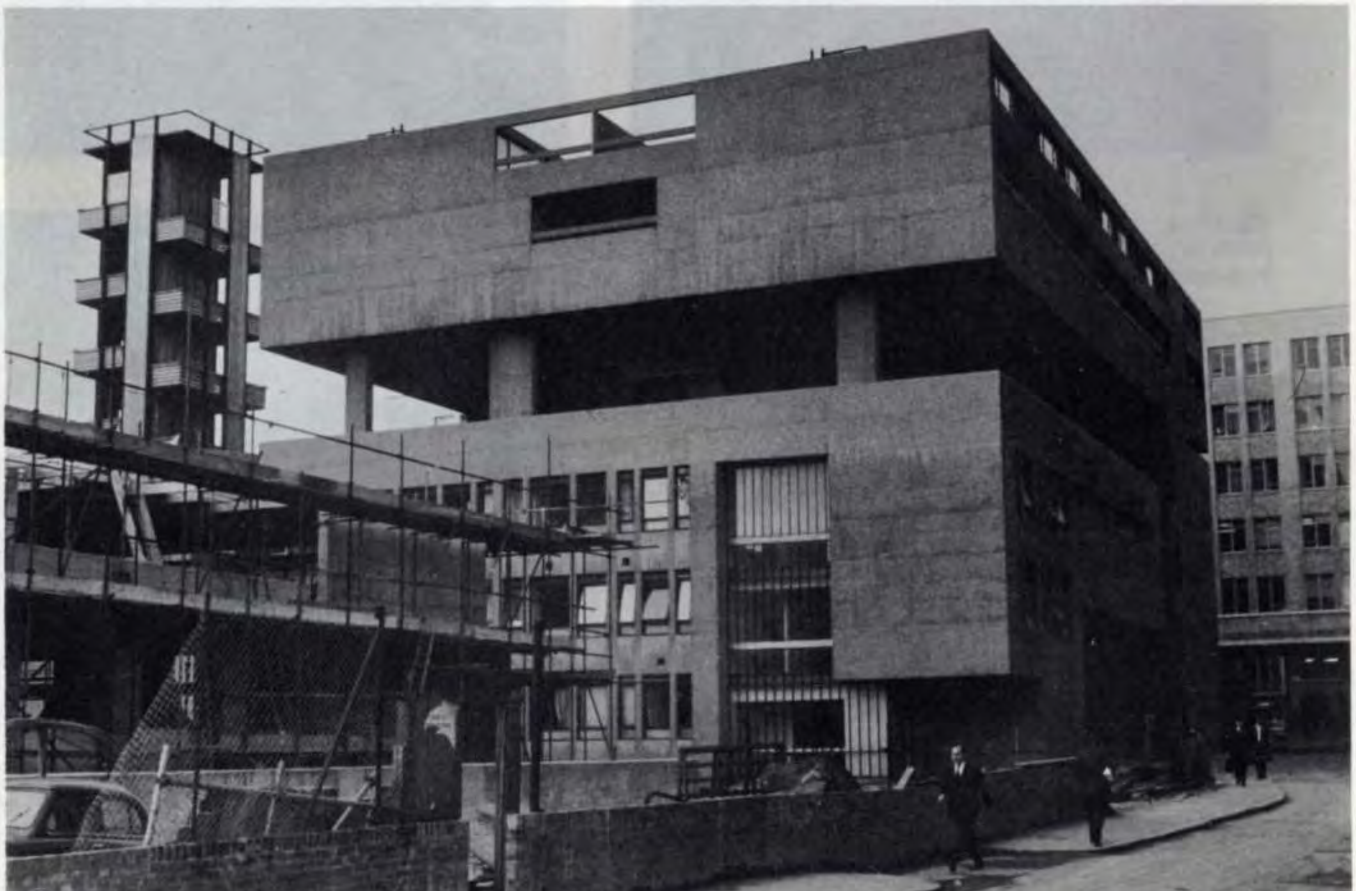

Fig.16
Block 11.
Edge of a pick-hammered cross-wall

Fig.17
Block 11.
Misuse of a point bit in pick-hammered work; tool has cut horizontal scores across the face

Fig.18
Public Services Building.
General view of building which is bush-hammered gravel concrete

Fig.19
Detail of Public Services Building.
Immediately to the right of the upper window alongside the fixed light a patch can be seen. This is where the concrete was cut back to line and shows the change in colour and texture which results when this is done to gravel concrete

Fig.20
Foam strip fixed to shuttering to improve watertightness

All the photographs in this article were taken by J. A. Waller.

19

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SOUTH BANK ARTS CENTRE

Architecture

Norman Engleback*

HISTORY

The opening of the Queen Elizabeth Hall on March 1 marked the completion of the first stage of the South Bank Arts Centre complex. In the immediate post-war period, when the Royal Festival Hall was conceived, it had always been the intention of the London County Council to provide not only the present Royal Festival Hall auditorium but a small hall which would act as a satisfactory vehicle for smaller scales of musical performance.

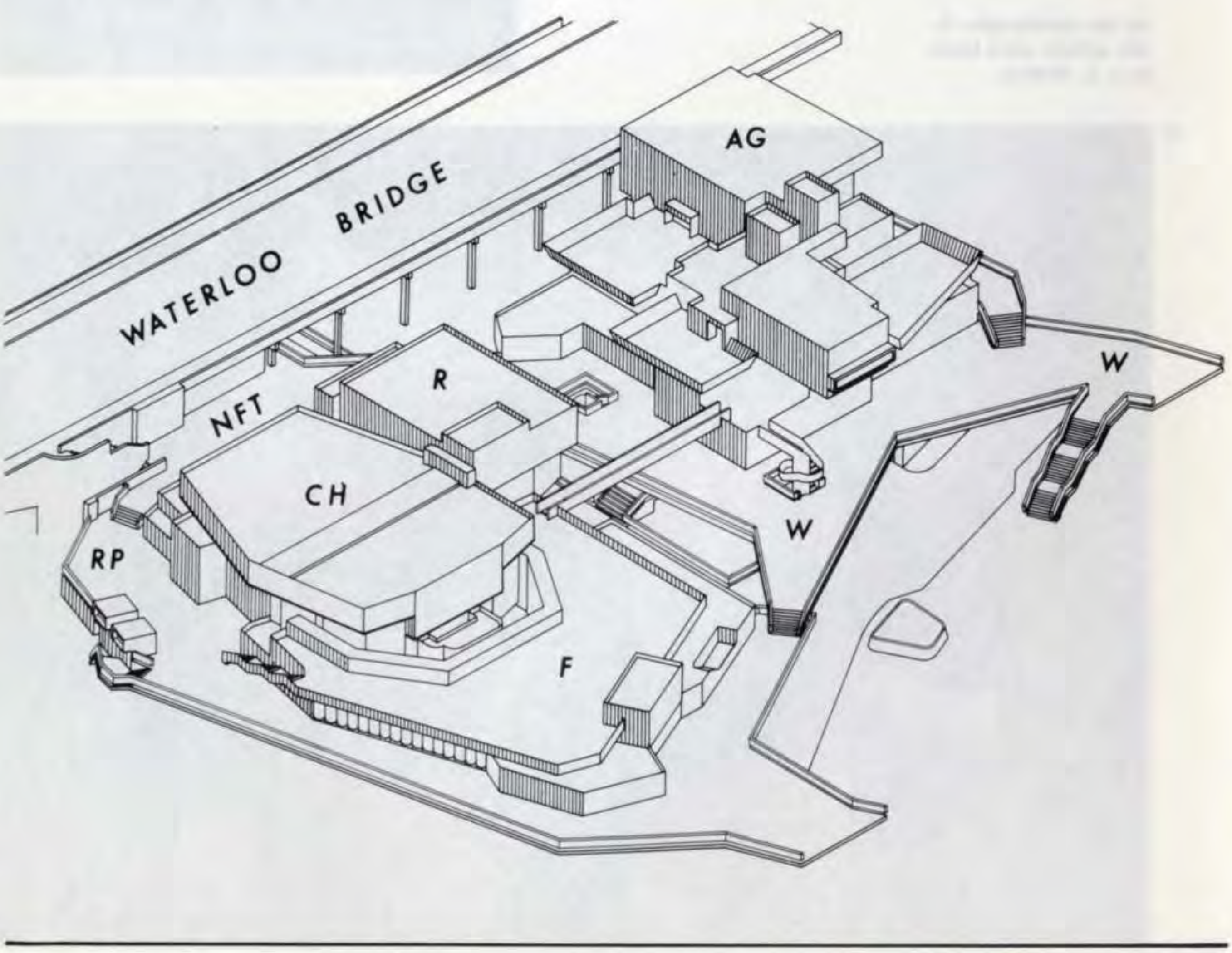
During the contract period for the Royal Festival Hall, foundation difficulties and a fixed deadline for the opening of the Festival of Britain in 1951 did not allow the original concept to be completed. A provision was made for the addition of the small hall immediately after the Festival closed, but by that time the country was in a period of financial stringency and it was not until the middle 50's that the small hall completion was examined in any detail. A scheme was produced to embody the new small hall auditorium in the Royal Festival Hall group, using a common foyer, but, with more intensive examination of the sound-proofing involved (primarily, by the location of the Bakerloo line immediately under the Festival Hall) it was felt that the risk of structure-borne sound was too great, and, as a consequence, a separate scheme was started.

A SCHEME

It was at this time that an Art Gallery was considered as part of the accommodation requirements. The Arts Council had been pressing for some time for a gallery suitable to take the travelling exhibitions, which normally displace works in the Tate Gallery, the Victoria and Albert Museum and other buildings. In November 1956 the first small concert hall and art gallery complex was published, and this took the form of a gallery on the Thames frontage of an area of 10,000 sq. ft., and a small concert hall which was convertible from an audience of 500 to an audience of 1,100. The convertibility was thought to be possible at that time by means of removable screens and curtains, and with a completely open concert hall plan, in which the foyers and circulation increased the natural volume of the space taken up by the seating.

* Greater London Council. Department of Architecture & Civic Design. Civic Design & General Division

Fig.1
Isometric view of the scheme in its final design stage.
Considerable change of details occurred subsequently. Compare with figures 2 and 3 (See Key on page 31)



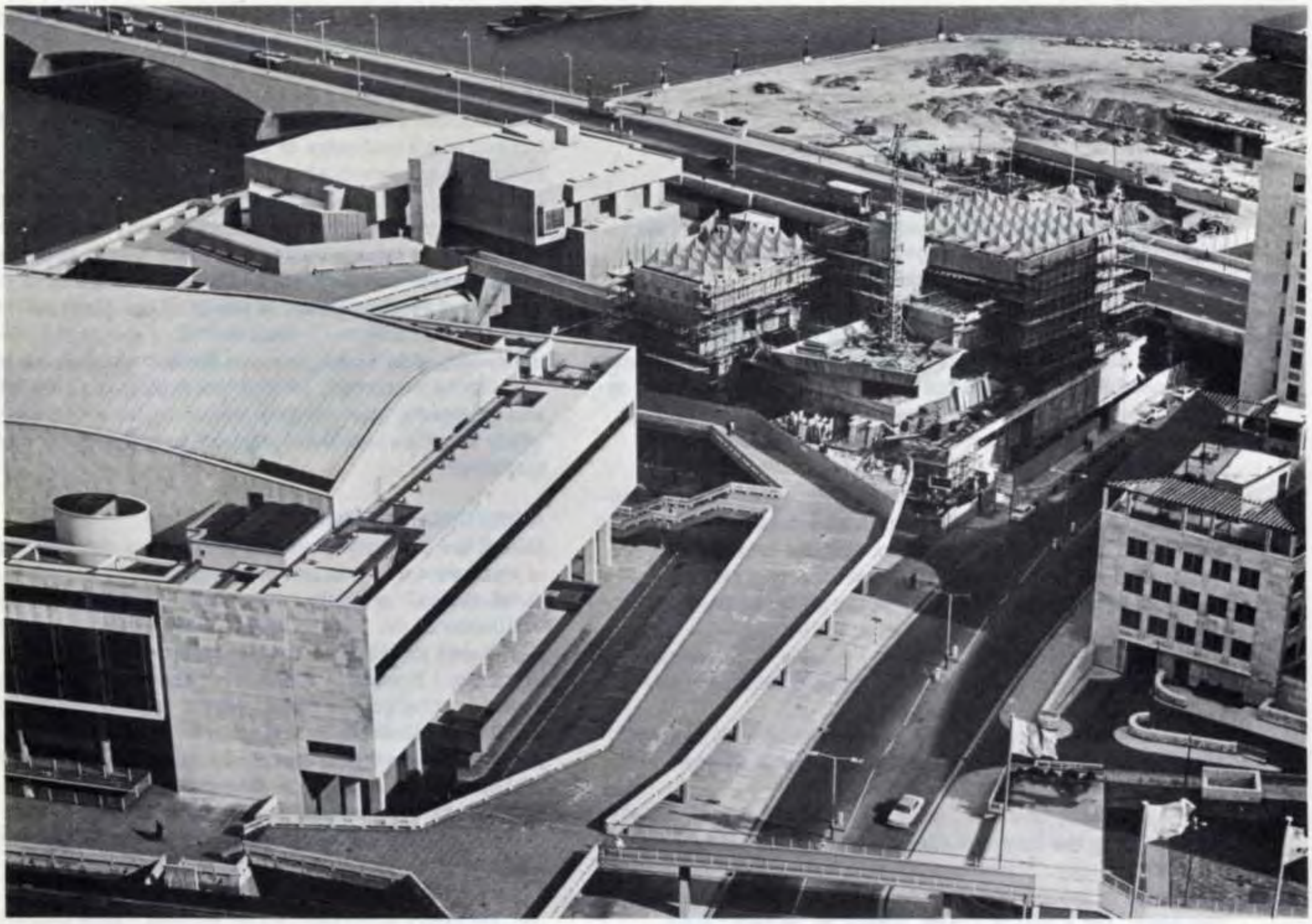


Fig.2
View of the site from the Shell tower.
Walkways and downstream prestressed footbridge over Belvedere Road in the foreground

Fig.3
Concert hall complex from Shell tower

ACOUSTICS

Again, after this scheme was published, there was another period of financial restriction, and it was during this time that experiments were carried out on the possibility of increasing the level of reverberation in the Royal Festival Hall. A number of natural methods were examined; the possibility of increasing the volume by removing the suspended ceiling, the effect of the removal of the low frequency absorbing timber panelling on the sides of the hall and the possibility of providing acoustical reinforcement close to the platform performers.

New concert halls were appearing in Europe, in particular in Germany, which benefited from the experiences of the original Royal Festival Hall design, and Dr Leo Beranek of the United States carried out a series of analytical tests on all the major halls in both Europe and America to find out why some were accepted by music critics more readily than others.

There was a common factor arising out of this study which linked all the halls which had particular musical and acoustical desirability. This was that the volume, in relation to the number of seats, was considerably greater than that considered necessary at the time the Royal Festival Hall was designed. A simple formula was established to show this variation, volume over the actual area of seating, referred to as $\frac{V}{S}$. The $\frac{V}{S}$ factor for the Royal Festival Hall is 33, but amongst the finest halls in Europe this figure increased substantially to 40 and beyond.

Large volumes, however, have inherent disadvantages with halls seating the larger audiences than those designed in the 19th century. Distances become critical and the problems of inter-reflection and echo are very real ones. However, for a hall of 1,100, which is, in fact, very similar to the audience sizes accommodated in the 19th century halls, it is possible to take a more radical view, and this formula of Beranek's was used to establish the volume of the new Queen Elizabeth Hall, ($\frac{V}{S}$ = 41) together with the advice of Hugh Creighton, acoustic consultant, and Peter Parkin of the Building Research Station, who was able to give precise physical data.

QUEEN ELIZABETH HALL

The musical requirements of the Queen Elizabeth Hall are limited to an orchestra of approximately 35 players and a choir to a maximum size of 50. In this way the limitation on the platform size allowed hard reflecting surfaces to be placed very close to the performers and, in addition, it was possible to physically reduce the height of the reflecting ceiling above the platform so that it contributed to the acoustical reinforcement of sound on the platform. It was still felt that with very weak soloists, the guitar, the clavicord, solo violin, etc., a further reinforcing system ought to be employed, so that the canopy of cast aluminium was proposed, immediately above the front of the platform, which would be retracted when larger musical forces were employed.

AUDIENCES AND SOUND

One of the problems facing a designer is the changing taste of audiences and musical performers over the years in which the hall is likely to be in use. The clarity and brilliance of the Royal Festival Hall, when it was first introduced in 1951, has now become the subject of some criticism. Nowadays there is a preference for a longer reverberation period and a greater degree of warmth. In the Queen Elizabeth Hall there has been an attempt to provide a degree of tunability by means of the use of HELMHOLTZ resonators, lining the walls and used solely as a means of absorbing below frequencies.

The HELMHOLTZ resonator is, in effect, an air-tight box with a slot or mouth through which the sound enters and is absorbed. The slot can be varied in size and in this way the frequency absorbed can be varied. It is possible to eliminate the effect of the resonator by blocking up the slot or mouth altogether, so that although the process of varying the great numbers of resonators installed in the Queen Elizabeth Hall is a formidable one, it is possible to overcome this without any alteration to the structure, or to the appearance of the design.

Fig.4
Upstream Belvedere Road footbridge and temporary walkway link

Theoretically it would be possible to produce HELMHOLTZ resonators in precast concrete and, in fact, a panel was fabricated by Ellis of Leicester to see whether this could be reasonably supported on the interior lining of the hall. There were, however, very substantial problems of weight involved, and it was decided to construct the resonators from a dense 2 in. block board laminate which would minimize moisture movement and maintain full air-tight conditions.
In writing about the design of the Queen Elizabeth Hall it may seem curious to some that one deals at length with the acoustical problems, right down to the details of absorption and platform design. This is the fundamental basis behind the design as it is now seen on the South Bank. It was designed, so to speak, inside out.
The primary need was to provide a hall for the highest standard of musical performance and for conditions which match these as far as the audience was concerned. The auditorium came first, shape and size determined by musical and sight-line requirements. The need to provide a satisfactory standard of structural installation against external noise determined the use of concrete as a material, 15 in. thickness as a minimum requirement, to achieve a decibel reduction of 55.
To strive for this degree of reduction without taking appropriate precautions against other sound paths led to further investigation on the movement of air conditioning ducts from potential noise sources in the plant room, air intakes to the auditorium itself and to the actual movement of the audience from the entrance foyers into the halls. Elaborate sound dampening ducts are expressed in the form of an overhanging cornice wrapped around the top of the auditorium structure; sound-proof lobbies between the foyer and the auditorium are expressed as couplings, linking the main design elements.
Problems of this kind are solved in aesthetic terms by the rationalization of their expression in the building form itself. The assembly of the elements of accommodation designed including those of an art gallery, both substantial in size, required particular care on this site. It would have been physically possible to assemble all these elements into a simple formal building, but this would have rivalled the mass of the Royal Festival Hall itself.

Fig.5
Downstream Belvedere Road footbridge and the walkway alongside the rear elevation of the Royal Festival Hall.

Fig.6
View of the Queen Elizabeth complex from the Belvedere Road pavement.

THE SITE
The site is not an easy one, it is dominated on all three sides by Waterloo Bridge, the Shell offices and the formality of the Royal Festival Hall and it is, moreover, shaped in the form of a wedge, which meant that to achieve a satisfactory relationship with one element would, inevitably, create problems with the other two.

THE TERRACES
In deciding to break down the buildings into their components, and expressing them, there was the basis of a solution. Some design elements could be suppressed below horizontal laminates of terraces. These form a complex pedestrian system which starts on the South Bank and links Waterloo Station concourse and Charing Cross Station without the intervening hazard of crossing roads. Moreover these terraces create the basis of a pedestrian network which is bound, in the future, to move into most of the central area activities. These horizontal elements, the pedestrian terraces, have been used to fuse the building forms together and to relate them to Waterloo Bridge and to the Royal Festival Hall.

FAIR-FACED CONCRETE
In a complex of this kind it becomes vital to maintain a careful and consistent standard of detailing and it is here that the use of fair-faced concrete was exploited to its maximum. Building forms, difficult in other materials, are perfectly possible in in situ concrete. Terraces which move in all directions can reasonably be solved by the mushroom slab techniques that have been used here without any concern about linear relationships. Detailing has been of a strong and vigorous kind and has been carried through from the Queen Elizabeth Hall to the Hayward Gallery so that the buildings, although having vastly different functions, have a common and simple vocabulary of materials and details which are readily identified.

THE WHOLE
Much has been made in recent criticism of the austere nature of this design but, in the context of this important reach of the river, against Waterloo Bridge and in the foreground of the more dominant Shell office buildings, this was the power and the handling necessary to achieve a significant contribution to the whole.

Structures

A. J. J. Bartak

'The site is not an easy one, it is dominated on all three sides by Waterloo Bridge, the Shell offices ...'

'It would have been physically possible to ... (produce) ... a simple formal building, but this would have rivalled the mass of the Royal Festival Hall ...'

'In deciding to break down the buildings into their components and expressing them, there was the basis of a solution.'

I purposely quote the architect as I consider that these sentences contain the precise statement of his almost impossible task and the basis for his, in my opinion, brilliant solution.

FORMS AND SHAPES
The adoption of the principle of functional fragmentation of the complex resulted in an exciting array of forms and shapes. At the same time, their realization became a predominantly engineering problem and presented the structural engineer with a formidable but at the same time exciting and challenging brief. There was nothing that was conventional or repetitive, nothing that could be solved by the rule book. It demanded a fresh and imaginative approach in the choice and use of materials, and in creation and application of new construction techniques.

MATERIALS AND METHODS
The variety and complexity of the forms implicit in the architectural concept demanded the general use of material

Fig.7
Entrance to the foyer
Queen Elizabeth Hall.

capable of being readily moulded, and therefore the structures are generally of reinforced concrete in situ construction. The main structures are of the rigid stressed skin type, designed to fulfil often very complex spanning and support conditions.

Extensive use is made of the off-the-shutter concrete, both externally and internally and often on both faces of a particular structural member.

THE SPECIFICATION

A comprehensive and detailed specification was prepared to cover all the aspects of this work, giving not only the precise definition of the desired end products but prescribing in detail the techniques which were to be employed on site in order to realize them. Considerable efforts were made at the beginning of the work to develop and perfect these techniques and to eliminate site difficulties. Of particular help in this respect was the fact that certain sections of walkways and both prestressed concrete footbridges over Belvedere Road, which were entirely in off-the-shutter concrete finish, had been included in the contract for the extension of the Royal Festival Hall, which started well in advance of the work of the main South Bank Development contract. This gave us the advantage of being able to start work on the Queen Elizabeth Hall and the Hayward Gallery with a great deal of teething troubles already eliminated.

SKILL AND WILLINGNESS

Close co-operation of everybody concerned, together with the considerable skill, enthusiasm, and the will to succeed displayed by the contractor, Higgs & Hill Ltd., throughout the job, produced the desired result.

At all stages of the design and preparation of working drawings, close work with the architect was needed to ensure that the construction joints were co-ordinated with the shutter patterns he wished to employ. On the other hand, construction problems had to be carefully examined in order to make it a practical job for the contractor.

When, as an example, one selects a typical stair structure which had patterned off-the-shutter finish on practically all faces (and there are many of these staircases) one may appreciate the intricacy of the problem and the patience and high standard of drawing office work necessary. In addition it was particularly important to minimize the effects of shrinkage and especially so as far as the externally exposed elements of the structure were concerned. In the main this was attempted by limiting the sizes of pours between the construction joints. For example, the walls were designed to be cast in panels not exceeding 25 ft. in length and 8 ft. high. A set of rules was established concerning reinforcement in various structural members, e.g. the minimum nominal longitudinal reinforcement in walls was set at 0.4%, the final amount depending on the geometry and the environment of the member.

All the horizontal reinforcement including the nominal wall reinforcement was of high yield deformed bars.

CONTRACTION JOINTS

Due to the complex geometry of the buildings it was generally not possible to provide expansion (or better called contraction) joints at conventional spacings. This necessitated additional reinforcement and careful detailing. In particular, wherever possible, the externally exposed parts of the structure were articulated from the main structures - and provided with their own expansion joints.

Needless to say when this stage of drawing office work was reached (i.e. a workable compromise between the various requirements just discussed was, as we thought, achieved) as often as not the initial structural conception for a given structure and the consequent analysis would be invalidated thereby, and we had to modify our initial conceptions.

GROUND CONDITIONS

As may be expected, the soil conditions were difficult. Obstacles in the form of foundations and other remains of many buildings which existed over the site at some time or other during the past centuries had to be removed or penetrated. These included the remains and rubble of buildings temporarily erected there during the 1950-1951 Festival of Britain. Of the older structures the most formidable obstacle was in the shape of the granite walls,

Fig.8
Street level entrance to
Queen Elizabeth Hall foyer.

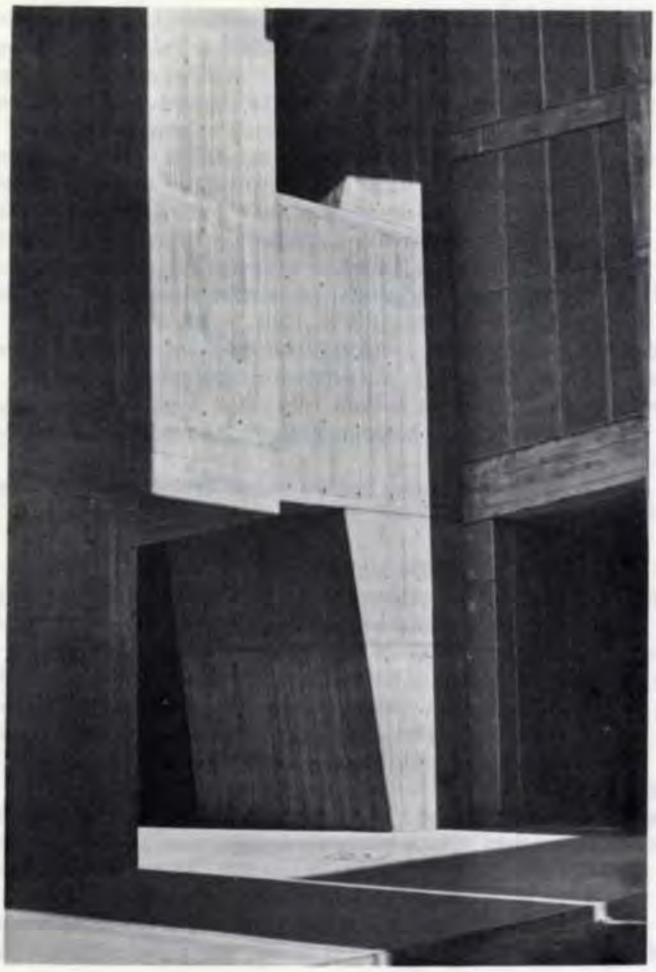


Fig.9
Foyer - Purcell Room link.

supported on timber piles, of the old Canterbury Dock which extended right across the site. In general, obstructions of all types plus building rubble derived from superstructures of various buildings, covered the whole site to a depth of 10 ft. - 15 ft. Below, there was a layer of ballast of varying thickness, overlaying a bed of London Clay at a level of approximately -19.00 Newlyn Datum, i.e. approximately 25-30 ft. below the ground level.

THE WATER TABLE

The water table was approximately at the Datum level, i.e. 10-12 ft. below the original surface of the site, and was marginally affected by the tidal variations of the river Thames.

PILES

Large diameter cylinder piles were thought to provide the best solution and were used to support all the structures, with the exception of Belvedere Road footbridges, and the sections of walkways running along the front and the rear elevations of the Royal Festival Hall. For these structures small diameter bored piles were adopted because of smaller loads involved and because it was necessary to excavate down to the ballast in the areas of pile caps in order to expose the existing services which abounded in these areas of the site. This procedure allowed the removal of the obstructions and consequently the use of small diameter piles.
The installation of the large diameter piles was carried out as a separate contract by Whatlings Ltd. during the period between April 1962 and January 1963 with Caldwell rigs.
Liner tubes, made in one piece of welded steel sheet, were used to penetrate the waterlogged ballast bed, a penetration of 5 ft. into London Clay proving sufficient to obtain a seal. The installation and recovery of the liners was greatly facilitated by the use of the Bade oscillating rig.
Altogether 296 large diameter piles were installed, of which 33 were 2 ft. in diameter, 190 of 3 ft. diameter, having 6 ft. or 7 ft. diameter under reams, and 73 of 4 ft. 6 in. diameter with 8 ft., 9 ft., 10 ft., or 11 ft. under reams. Maximum load of 470 tons was carried by a 4 ft. 6 in. diameter shaft pile having a 10 ft. under ream, founded at -60.00 o.d., i.e. approximately 40 ft. into the London Clay. All piles were designed for equal calculated settlement, of $\frac{3}{4}$ in. for the Concert Hall and $\frac{1}{2}$ in. for the Art Gallery Complex.
Now for the detailed description of the structures.

QUEEN ELIZABETH HALL

The Concert Hall is an in situ reinforced concrete box, approximately 154 ft. long by 86 ft. wide by 70 ft. high. The structure is supported on a foundation of large diameter concrete cylinders. The rear of the auditorium is structurally a propped cantilever, two large columns situated one on each side wall at the start of the cantilevered section are the main supports and carry approximately 2,500 tons each.

WALLS

The walls of the hall are themselves structural members, 15 in. thick and in some areas are heavily reinforced. The walls, ducts and columns have both exposed Cornish

Fig.10
A view of the Purcell Room cantilever.
Note the plant room above and
its supporting structure.
Prestressed concrete footbridge connecting
high pedestrian levels in the foreground.

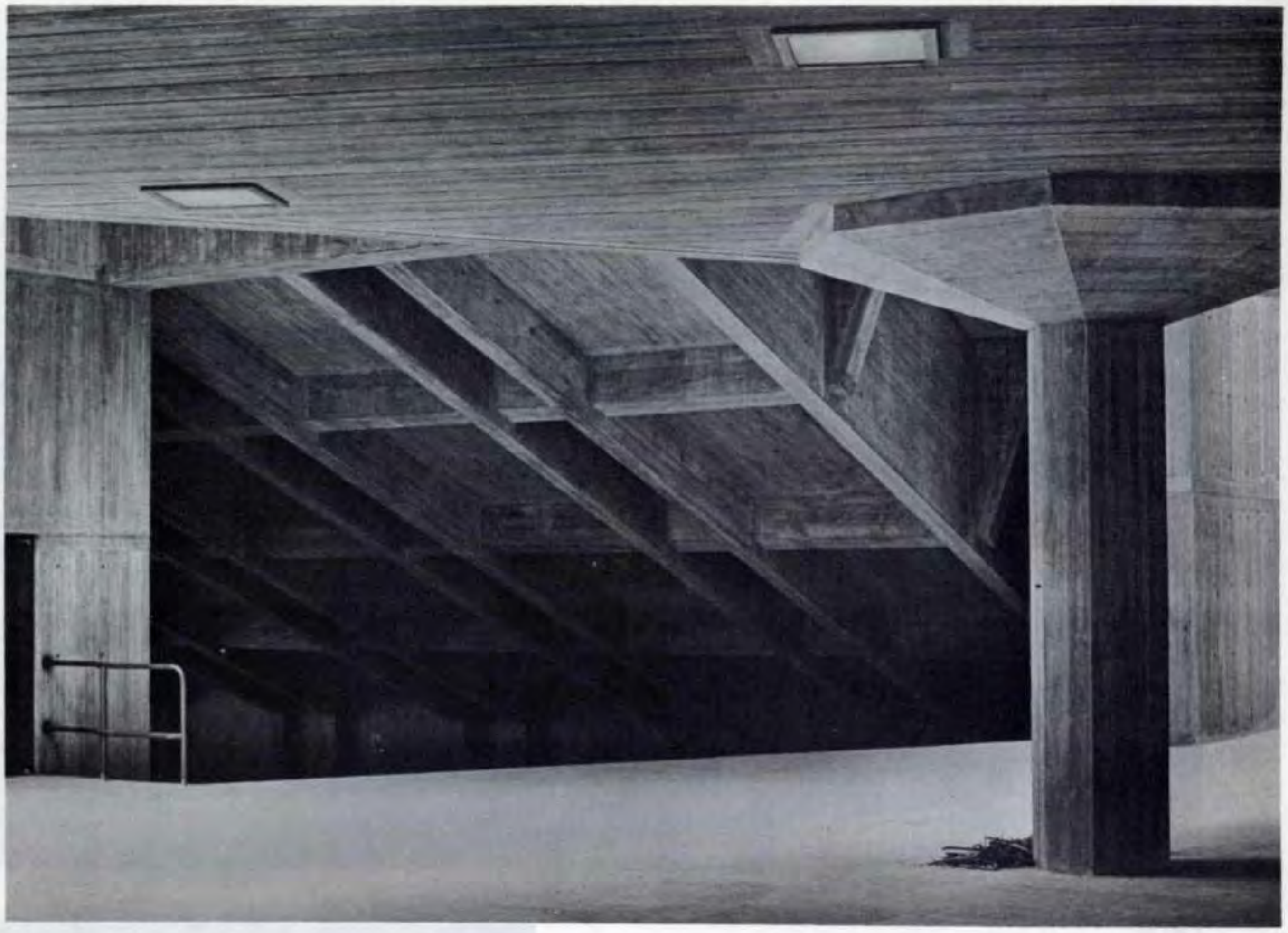
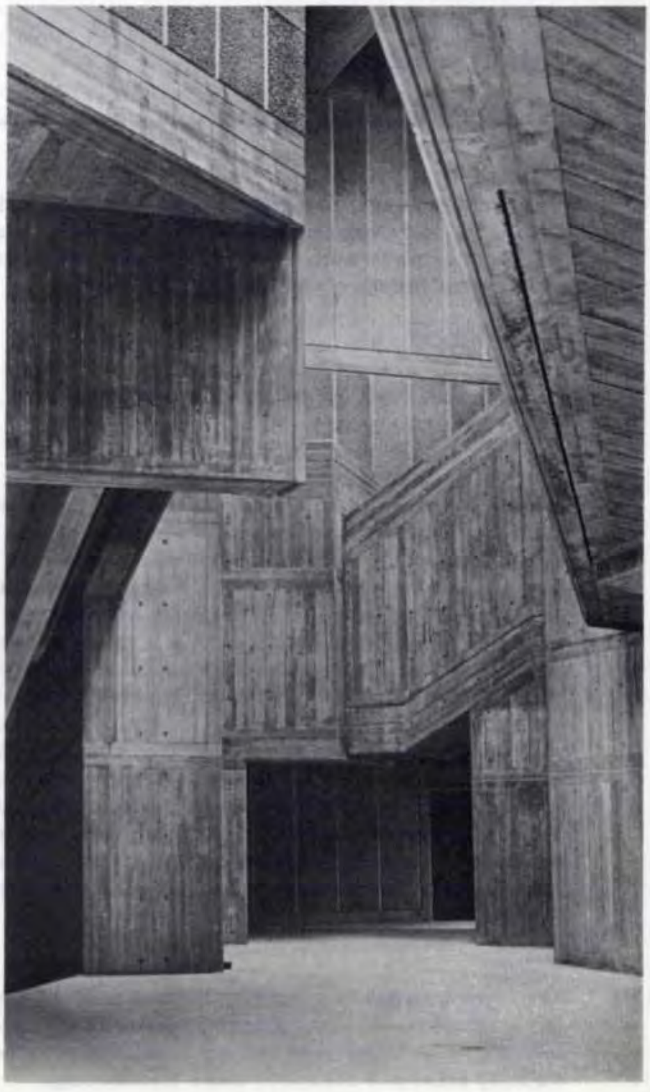


Fig.11
Underside of the cantilevered rear section of the Queen Elizabeth Hall auditorium

Fig.12
Foyer auditorium link



granite aggregate precast cladding and fair-faced finishes externally. The resonators and internal cladding to walls are of timber, supported on reinforced concrete exposed face corbels, from the main walls. Internally, the stage end and flanking walls have off-shutter finish for the entire height, the side walls up to the level of the corbels.

ROOF
The roof of the auditorium consists of a 15 in. reinforced concrete slab supported on reinforced concrete box beams spanning 85 ft. on to the side walls. Each box beam is made up of two beams 13 ft. deep by 18 in. wide with a 15 in. top flange and a 5 in. bottom flange.
9 in. x 21 in. precast beams spaced approximately at 5 ft. centres and spanning between box beams support a fibrous plaster ceiling.

FLOOR
The floor is supported on sloping box beams, spanning the length of the auditorium and supported on the rear wall and over cross-walls in the basement. The boxes are made up of two beams, approximately 9 ft. deep by 12 in. wide, with a 12 in. top flange. There are five of these beams, three of which contain the extract ducts from the hall. There is a sloping 12 in. reinforced concrete slab spanning between the box beams approximately 2 ft. above the soffit of the main beams, over the cantilever section. Shaped precast floor planks, spanning between the box beams, were to support the seats. In the event, at the contractor's request, these slabs were constructed in situ.

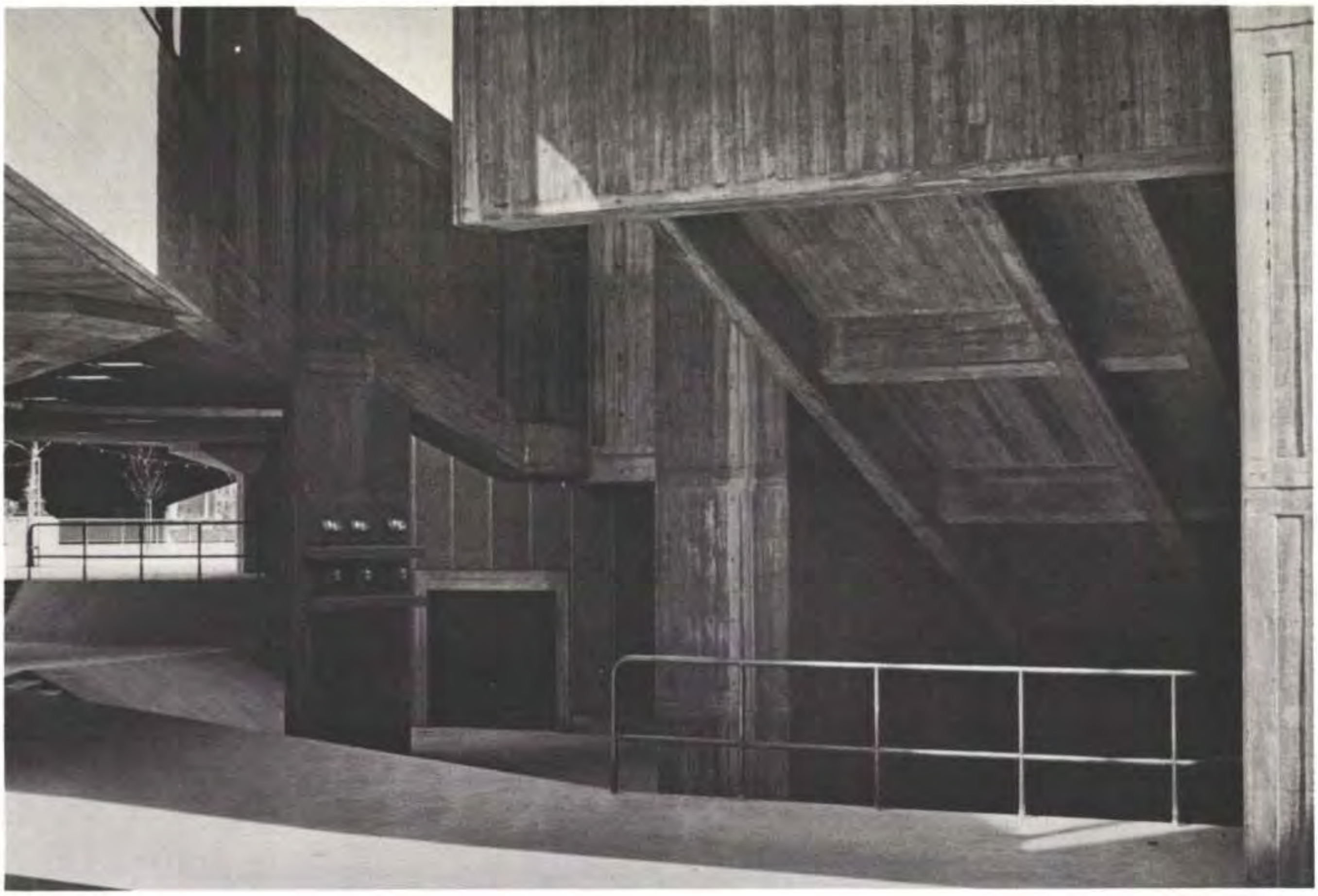


Fig.13
Foyer auditorium link

Fig.14
Typical external staircase

BASEMENT
The basement area, at approximately 4.00 level under the auditorium and extending between the main side columns and the back stage wall, is of a double skin construction to prevent any moisture penetration to the ducts.

PLANT ROOM
The plant room is a concrete box supported on three sides by reinforced concrete walls and at a height of 55 ft. above general ground level.

RECITAL ROOM
The recital room, also a concrete box, fits under the plant room and between the three walls mentioned above, but projects out of the open fourth side as a cantilever. There is a 3 in. cavity between the plant room structure and the recital room structure, to prevent the transmission of unwanted sound. Both buildings have a common foundation of large diameter cylinders. The walls and roof of the recital room are 15 in. reinforced concrete and the roof slab is supported by box beams spanning between the side walls, the arrangement being somewhat similar to that used in the Concert Hall. The stepped slabs supporting the seats were precast and fixed to the longitudinal upstand reinforced concrete beams. The cantilevered portion of the floor is enclosed at the bottom by a 12 in. reinforced concrete slab, the interspace is used to contain service ducts.

FOYER
The foyer consists of a flat slab terrace at 47.00 level and one at 28.00 level, both supported on mushroom-type columns. The latter is of similar construction to the walkway slabs and described under that heading.

FOOTBRIDGE
The high level terraces of the foyer and the art gallery are connected by a prestressed concrete post-tensioned footbridge spanning 90 ft. The bridge is in the form of a single simply supported span, and has a trough type cross-section. Tendons are of the seven-strand type. C.C.L. anchorages and equipment were used.

THE ART GALLERY COMPLEX
The work on the Art Gallery (which will be known as the Hayward Gallery when it is commissioned early next year) is in its final stages. It will feature five exhibition galleries, three external sculpture courts and a car park at the ground level.

WALKWAYS AND FOOTBRIDGES
The walkways consist of a system running parallel to the Belvedere Road on one side and to the River Thames on the other side of the Royal Festival Hall, with the necessary access staircases. In addition there are two prestressed concrete footbridges over the Belvedere Road which connect the walkway system to the access points provided in the Shell complex.

THE WALKWAYS
These are of reinforced concrete flat slab construction. The slabs themselves are of 2 ft. overall structural depth and are cellular, the voids being formed by means of corrugated cardboard boxes. The slabs are supported on octagonal mushroom columns, the circumscribed diameter being 2 ft. 9 in. and the height above the ground varying up to a maximum of approximately 18 ft. All the reinforced concrete work is exposed face. The columns were cast in one operation including the mushroom.
It may be of interest to mention the procedure which was proposed and carried out successfully for the construction of cellular walkway slabs. After fixing the reinforcement, the bottom 4 in. concrete slab was cast. Corrugated cardboard boxes were then placed upon it and tied to the rib steel after which the ribs and the top slab were poured.

THE FOOTBRIDGES
The two footbridges cross the Belvedere Road, one each side of Hungerford Bridge. Both bridges are of prestressed post-tensioned concrete. They were designed as two-pin portal frames, with cantilevers projecting at both ends. The depth of each deck varies throughout its length. The walking surfaces have a finish of mastic asphalt but everywhere else the finish is exposed concrete.
The C.C.L. prestressing system was used. Each cable consisted of twelve .276 in. diameter high tensile steel wires. The anchorages were C.C.L. spiral anchorages. All wires in the columns were tensioned from the top only. All wires in the decks were tensioned from both ends. As the Shell walkways already existed, special pockets have been left in order to tension the wires at that end.

THE UPSTREAM BRIDGE
The centre span is 53 ft. 6 in. and the cantilever spans are 20 ft. 6 in. and 12 ft. 6 in. The overall width is 16 ft. The two foundations contained 7 piles and 6 piles respectively. All piles were raked, and 18 in. in diameter. There were 22 prestressing cables in the deck, and 14 in each column.

THE DOWNSTREAM BRIDGE
The main span is 64 ft. 6 in. and the cantilever spans are 20 ft. 6 in. and 20 ft. 3 in. The overall width is 12 ft. The foundation at the north end contained 6 piles. The south end column is supported by the retaining wall of the Shell building through a mild steel bearing plate. There were 20 prestressing cables in the deck, and 12 in each column.

THE TEMPORARY WALKWAY
This connects the upstream Belvedere Road footbridge to the permanent walkway terminating at the downstream side of the Hungerford Bridge. It consists of open or parapet-type truss girders in structural steel, with the exception of the span within an arch of the Hunterford Bridge, which is of through type. This span and its portal frame supports were designed to enable it to be disconnected easily and lowered to the ground for rapid removal, should an urgent need arise to support or repair the arch of Hungerford Bridge above. The removal would be by means of rollers.

Fig.15
Typical external staircase.

To improve the aesthetics, rectangular hollow sections have been used in the trusses. Shop joints were welded with bolted site joints.

Architects:	Greater London Council. Department of Architecture & Civic Design. Civic Design & General Division
Quantity Surveyors:	Harry Trinick & Partners
Services engineers:	Greater London Council. Mechanical and Electrical Engineer's Department
Contractors:	
Belvedere Road Footbridges and sections of walkways included in the Royal Festival Hall extension contract:	Higgs & Hill Ltd.
Sub-contractors for the small diameter bored piles for the above:	Soil Mechanics Ltd.
Contractors for the large diameter pile foundations contract for the Concert Hall and Art Gallery:	Whatlings (Foundations) Ltd.
General contractor for the Concert Hall and Art Gallery contract:	Higgs & Hill Ltd.
General contractor for temporary walkway:	Whyatt (Builders) Ltd.
Steelwork erection and fabrication for temporary walkway:	Structural & Marine (Engineers) Ltd.

Fig. 16
Vertical duct to the main plant room.

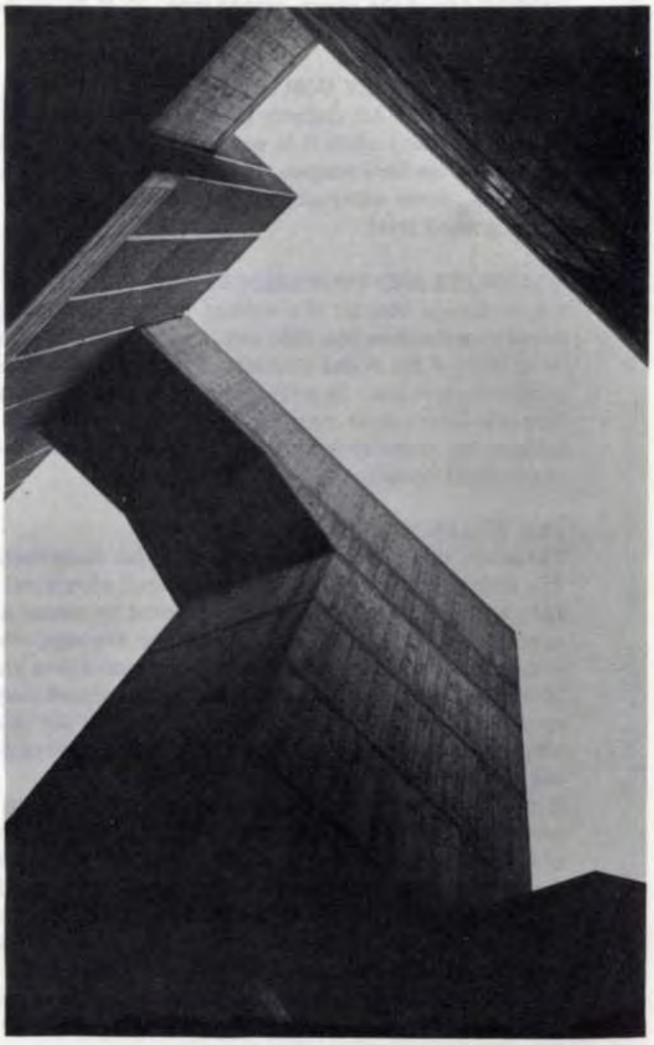
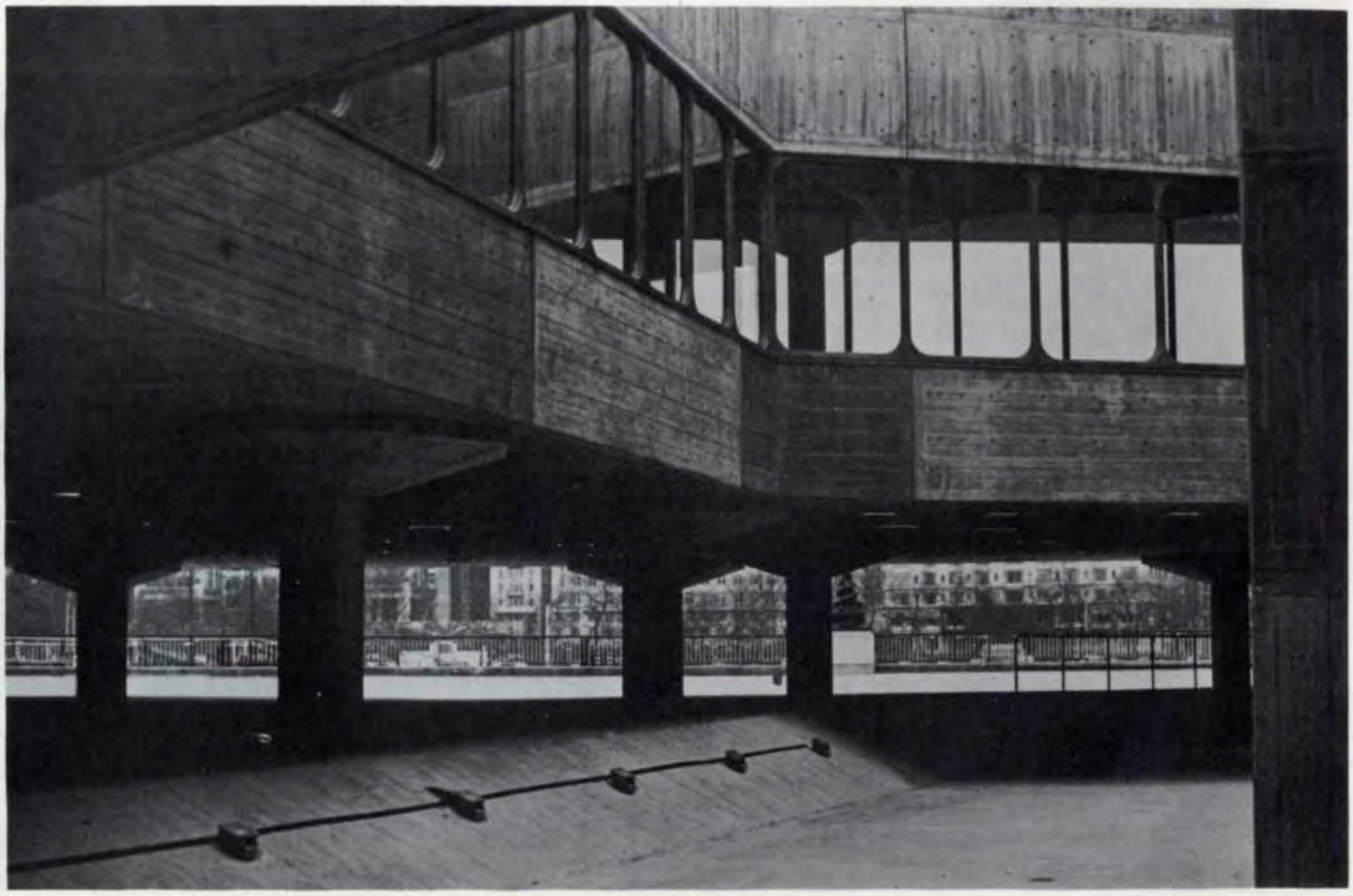


Fig. 17
Foyer from internal courtyard.
Note the articulation of the periphery walls.



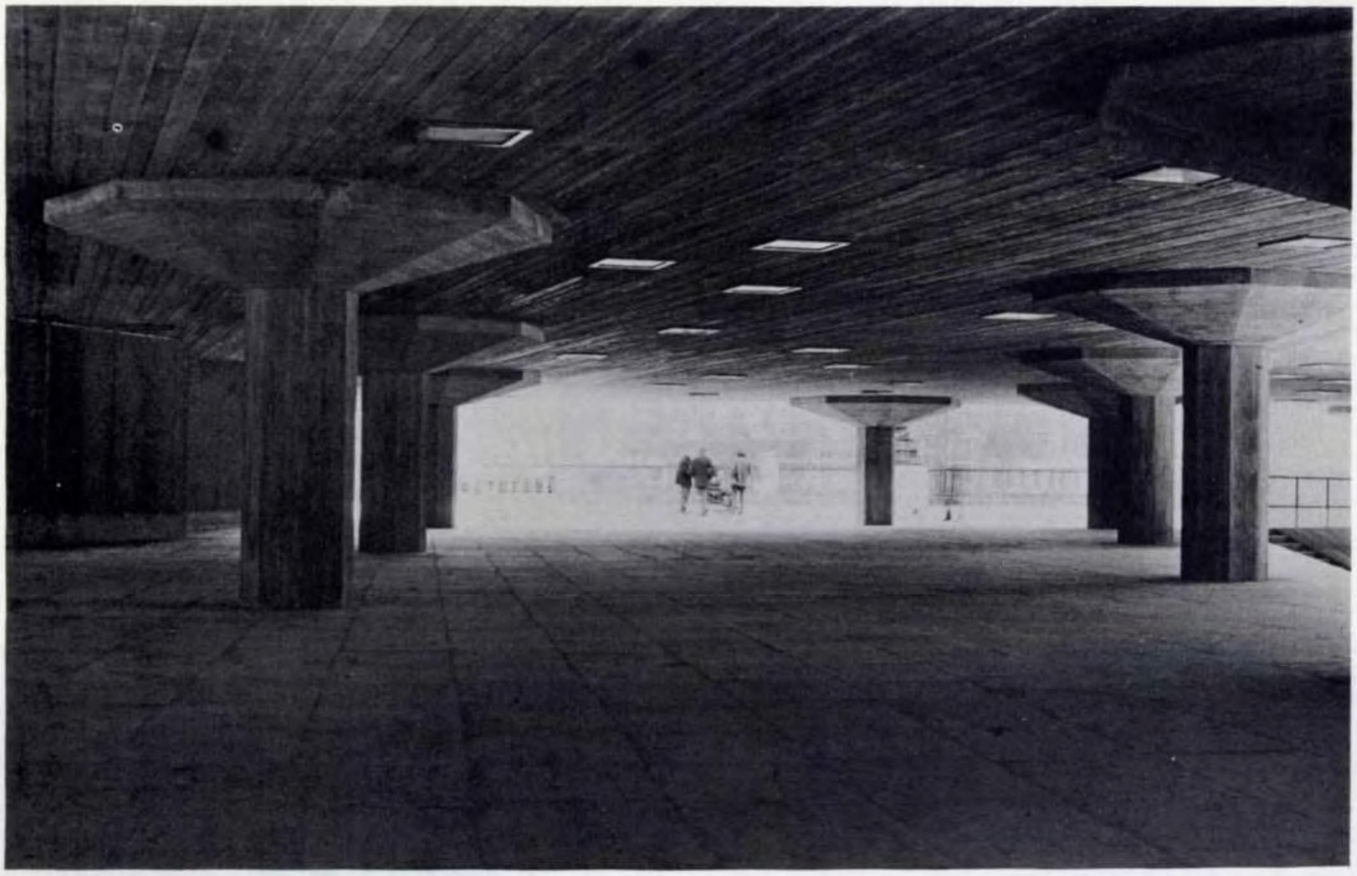


Fig.18
'Catacombs'

Fig.19
Stage end.
Typical combination of
external finishes.
Off-shutter concrete
and precast exposed
Cornish aggregate panels

All the photographs in this article were taken by K.C. Anthony.

Key to Figure 1 on page 20

AG - Art gallery

CH - Concert hall

F - Foyer

NFT - National Film Theatre

R - Recital room and plant room

RP - Refrigeration plant room

W - Walkways

Designed by Desmond Wyeth MSIA
Printed in England by John B. Reed Ltd. Windsor Berkshire