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Editor:
David J. Brown
Art Editor:
Desmond Wyeth FCSD
Deputy Editor:
Hélène Murphy
Editorial Assistant:
Joanne Worrall

Front cover: Kwun Tong Bypass, Hong Kong, under construction (Photo: L.M. Lui)

Back cover: Clerestory detail, National Gallery Sainsbury Wing (Photo: Peter Mackinven)

Kwun Tong Bypass, Hong Kong
Klaus Falbe-Hansen

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Ove Arup & Partners Hong Kong designed the structure, including foundations, columns, and precast segmental deck, for 3.7km of elevated highway on the Kwun Tong waterfront, alongside Kai Tak airport in Kowloon Bay.

Soda ash project, Sua Pan, Botswana
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Ove Arup were responsible for the civil, structural, building, foundation, and infrastructure engineering of this new plant to recover industrial soda ash from a 150km^2 wellfield in a remote corner of Southern Africa.

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Ove Arup & Partners undertook the structure and services design for the new building in Trafalgar Square. This article concentrates on the rigorous environmental systems developed for the safe display and storage of some 240 early Renaissance paintings in a variety of media.

Kwun Tong Bypass, Hong Kong

Klaus Falbe-Hansen

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Introduction

Kwun Tong Bypass is part of Route 6, the 18km high speed link between Hong Kong Island, Kowloon, and Sha Tin in the New Territories. The 4.8km Bypass connects two tunnels: Eastern Harbour Tunnel between the Island and Kowloon, and the Tate's Cairn Tunnel to Sha Tin. It was contractually split into three phases of which only II and III were tendered competitively, Phase I being completed as entrusted work by the Harbour Tunnel contractor, due to early completion of the tunnel. This opened for traffic in July 1989, 18 months ahead of the Government's original plan, which put great pressure on completing the rest of the link. Phase II is a 2.3km dual three-lane viaduct, partly over water, with four elevated ramps totalling 0.9km in length. Phase III is 1.4km long with one 0.2km long ramp. Dragages et Travaux Publics, a subsidiary of the French contractor Bouygues, prequalified in September 1988 in a 90/10 Joint Venture with Bachy Soletanche to tender for both phases, and asked Ove Arup & Partners Hong Kong to assist them during the tender period.

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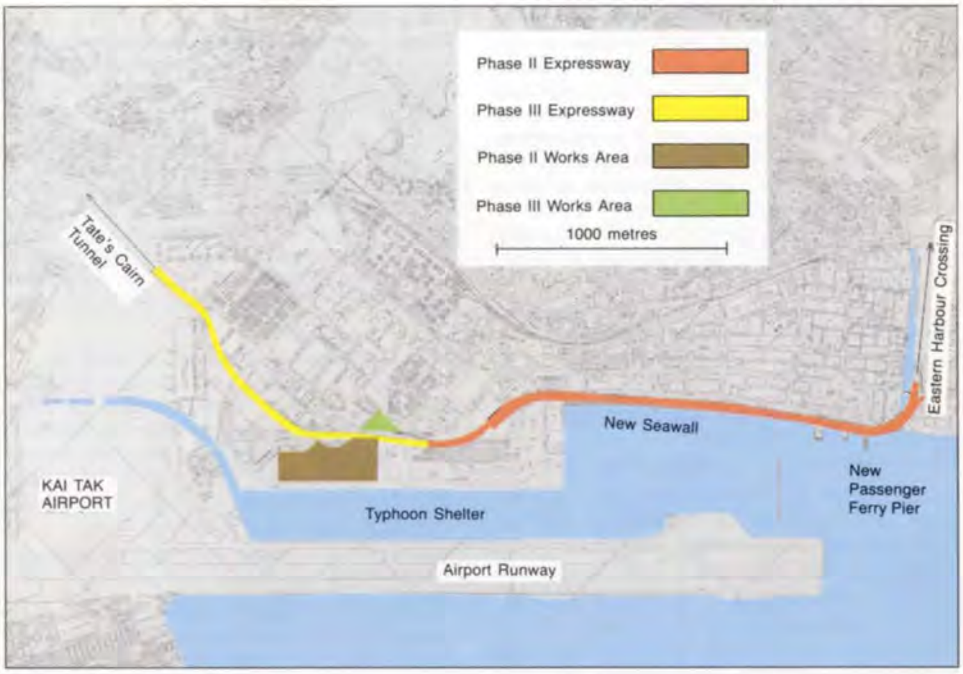


Phase II tender design

The 'conforming scheme'

The engineer for Phase II, Freeman Fox Maunsell (FFM), issued tender documents in October 1988. The tender period was six weeks. In their 'conforming scheme' design, FFM had divided the viaduct into three sections: two geometrically complicated end sections A and C, and a central, almost straight, section B, parallel to Kai Tak runway and mainly over water.

Sections A and C, with sharp, horizontal, 190m radius curves and widening decks to accommodate the slip-road bifurcations, were to be of prestressed concrete, constructed in situ by the span-by-span method. The cross-section was a multi-cell box 25m-43m wide for the two carriageways, and a 6m-8m wide single-cell box for the ramps; construction depth was 2.0m, except for one ramp which clearance problems reduced to 1.8m. Span lengths varied between 30m and 40m.

Section B was to be in precast segments with match-cast epoxy-glued joints erected span-by-span. The cross-section consisted of two separate boxes, one for each carriageway. The boxes were single-cell and 12.5m wide for most of Section B, but towards Section A where the deck widens to 2 × 15m, two-cell boxes were used. The construction depth was 2.25m and the span length was 40m.

The foundations consisted of 1.5m-1.8m diameter bored piles to bedrock, with pile lengths in the range 30m to 60m.

Comparing unit quantities in the three sections of the conforming scheme showed a lack of efficiency in Sections A and C when compared with the precast Section B, where quantities per m^2 deck were about 30% less. It was therefore clear that an alternative design extending the use of the precast segmental construction would be economically attractive.

The erection technique envisaged in the conforming scheme utilized an underslung launching girder for the precast segments of Section B. Although this method is efficient for the construction of long straight decks, it is not easily adaptable for strongly curved alignments. Dragages favoured the use of an overhead launching girder to erect the segments by the balanced-cantilever system; the girder could also be adapted to cope with the changing horizontal deck alignment. By pivoting it on two sets of transverse running rails it would be possible to move it sideways and rotate it relative to the deck centre-line when placing a pair of segments. Based on this method, a precast segmental alternative design was developed for the entire viaduct.

3. Launching girder near junction of Phases II and III, January 1990.

The alternative scheme

The alternative segmental scheme used two basic box types, a large one typically 12.7m wide with cantilevers for the carriageways, and a small box typically 6.2m wide with cantilevers for the ramps. Where carriageways and ramps merged, the cross-section comprised large and small boxes connected through 0.5m wide in situ stitches between the cantilever slabs. The length of the box cantilevers varied according to the required overall deck width and the length of segments varied with span length. Limiting segment dimensions — in particular the maximum segment weight of 80 tonnes — were fixed by Dragages so that it would be possible to use, with only minor modifications, the launching girder which had just successfully completed the construction of the Viaduc de Sylans near Chamonix in France.

The Phase II viaduct was divided into several independent expansion units, the length of which depended on earthquake design requirements and deck geometry. The longest were 240m, consisting of six 40m spans on the straight central section B of the viaduct. At tender stage a detailed preliminary design was carried out for one of these six-span units to establish reliable and economical quantities per m^2 of bridge deck for concrete, reinforcement and prestressing steel. The benchmark for these quantities, with due consideration being given to the design standards of Hong Kong, was what Bouygues had been able to achieve for bridges erected in a similar way on design-and-construct contracts in France. The quantities found for the six-span unit were extrapolated and applied to all the remaining expansion units to provide quantities of principal materials for the complete viaduct.

In the conforming scheme, all bridge bearings were of the mechanical pot type. The Arup design used the more economical elastomeric bearings wherever possible, and pot bearings only where earthquake restraint was required or where the vertical load exceeded 10 000kN. Only minor changes were made to the column shapes during the tender phase, but the design resulted in reduced reinforcement quantities.

Arups carried out an alternative foundation design for the whole viaduct based on the reduced self-weight of the alternative deck. For the land-based pile caps barrettes were used, typically 1.0m × 2.8m in cross section, instead of the bored piles. A barrette — a rectangular pile constructed under bentonite using the diaphragm-wall technique — can be orientated to resist design loads in the most efficient way, resulting in reduced reinforcement quantities. We proposed founding the barrettes in the dense decomposed granite with SPT value >200, instead of in bedrock, and to mobilize their shaft friction. This generally led to shorter piles in the alternative scheme. For the marine pile caps we retained the bored piles of the conforming scheme. The alternative scheme represented a substantial saving in quantities compared to the conforming scheme; concrete was reduced by 15%, reinforcement by 50%, and prestress by 10%.

The contract for Phase II contained, apart from the viaduct, substantial other works:

(1) extensive ground level road works
(2) 1.5km of trunk sewer diversion
(3) 0.5km of new seawall with reclamation in the Kowloon Typhoon Shelter
(4) a new Kowloon Passenger Ferry pier.

Arups carried out alternative designs for the trunk sewer and for the foundations and the main deck of the Passenger Ferry Pier.

The tender

Tenders were submitted in December 1988, with Dragages coming lowest at HK$770M for their alternative scheme. For the conforming scheme, the lowest bid of HK$835M was also submitted by Dragages. They were awarded the contract in January 1989 on the basis of the alternative scheme and Arups' Hong Kong office was commissioned to carry out the detailed design for the contractor. Completion was in July 1991.

Phase III tender design

The conforming scheme

the tender documents for Phase III were issued in November 1988 by the Highways Department's Kowloon Office. The whole of this 1.4km long, strongly curved, overland viaduct was designed as in situ prestressed concrete constructed span-by-span. The cross-section was a single multi-cell box, 20m wide and 2.25m deep, with span lengths from 26m-46m. In addition, there was a 0.2km long ramp, generically part of Phase II, and designed by the Phase II engineer FFM. The foundations were 1.8m diameter bored piles to bedrock.

The alternative scheme

Arups carried out an alternative foundation design using 1.0m × 2.8m barrettes instead of bored piles. Our Phase II quantities for precast segmental construction were extrapolated and used for the Phase III deck. The savings in quantities relative to the conforming scheme were again substantial: concrete reduced by 20%, reinforcement by 50% and prestressing steel by 30%. However, there was one major obstacle to the alternative system and that was the lack of a works area for a precasting yard. Only if Phases II and III were combined, and the works area set aside for Phase II became available, would a precast segmental solution be feasible for Phase III. Dragages decided to submit the alternative with their tender, but with the qualification that the group was also awarded Phase II.

The tender

Tenders were submitted in December 1988. Dragages were not lowest for the conforming scheme and had not put a price against their alternative scheme, only offering it for negotiation in case the group was awarded Phase II. However in February 1989 the contract for Phase III was awarded to Dragages at a value of HK$280M with completion in July 1991. Arups' Hong Kong office was again asked to carry out the detailed design for the contractor, and Tony Gee Chappelle HK Ltd was appointed to act as the independent checking engineer for both Phases II and III.

Detailed design: Phases II and III

The Phase II contract was the largest ever to have been awarded by the Hong Kong Highways Department, and it was the first time they had accepted an alternative design for a major scheme. It was also the first time that precast segmental construction was to be used, not only in Hong Kong, but in Southeast Asia.

Detailed design, based on *BS5400* and the HK Civil Engineering Manual, started March 1989.

The award of Phase III had important consequences for programme and design. Phases II and III had been awarded as two separate contracts and required therefore a launching girder each; the contractor however wanted for obvious reasons to use the same girder for both.

The alternative scheme and the contractor's initial erection programme for the 1500 segments of Phase II were based on a four-day erection cycle for a pair of parallel cantilevers, equivalent to 40m length of dual carriageway. In order to fit the erection of Phase III, requiring 700 segments, into the programme, using only one launching girder, the contractor had to accelerate the erection cycle to three days. Fig. 4 shows the principal steps in the four-day erection cycle of a pair of parallel cantilevers 1 and 2:

- Move girder forward (2)
- Position pier segments on cantilever 2 (3)
- Move girder sideways and position pier segments on cantilever 1 (4)
- Move girder forward and construct balanced cantilever 1 (5-7)
- Move girder sideways and construct balanced cantilever 2
- Construct 0.2m wide in situ closing stitch.

During each of the (normally four) cantilevering stages, temporary Dywidag bars hold the last pair of segments in position until the epoxy glue has set. Then the permanent top cables are installed and stressed, and the next pair of segments can be attached. The permanent cables were, in the alternative scheme, anchored in the end face of the segments with the installation and stressing of the cables carried out from a platform supported by the launching girder; in a three-day cycle this operation became critical, and the contractor decided instead to anchor the top cables in a rib inside the box. The installation and stressing of the top cables could now be carried out without the aid of the launching girder, which could be moved sideways to place a pair of segments on cantilever 2 while the stressing was carried out on cantilever 1. The two cantilevers could now be constructed more quickly and simultaneously, instead of successively. It took the contractor seven months to convince the Highways Department that this revised method was feasible and to have the use of one launching girder accepted.

Appearance

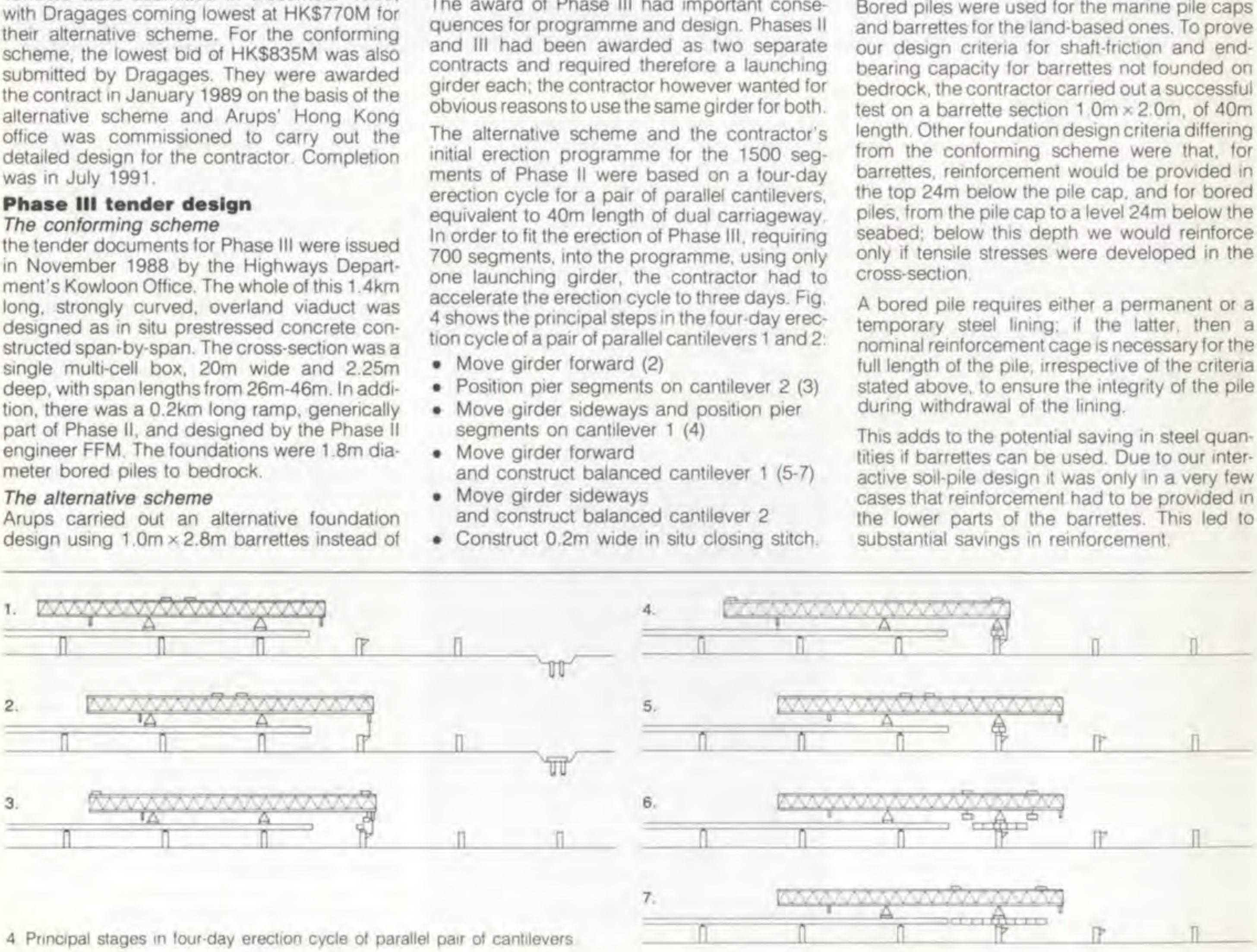
Because the structures were to be imposed on a compact urban area, their appearance was important. The complete scheme was subject to the approval of ACABAS, which has a role similar to that of the Royal Fine Art Commission in the UK. A good deal of time and effort was spent on purely aesthetic aspects such as the locations and shapes of the columns, the appearance of the structure when seen from below, the positioning of deck drainage pipes where these had to be unavoidably attached to the underside of the deck, and the shape of the parapets.

Foundations

Bored piles were used for the marine pile caps and barrettes for the land-based ones. To prove our design criteria for shaft-friction and end-bearing capacity for barrettes not founded on bedrock, the contractor carried out a successful test on a barrette section 1.0m × 2.0m, of 40m length. Other foundation design criteria differing from the conforming scheme were that, for barrettes, reinforcement would be provided in the top 24m below the pile cap, and for bored piles, from the pile cap to a level 24m below the seabed; below this depth we would reinforce only if tensile stresses were developed in the cross-section.

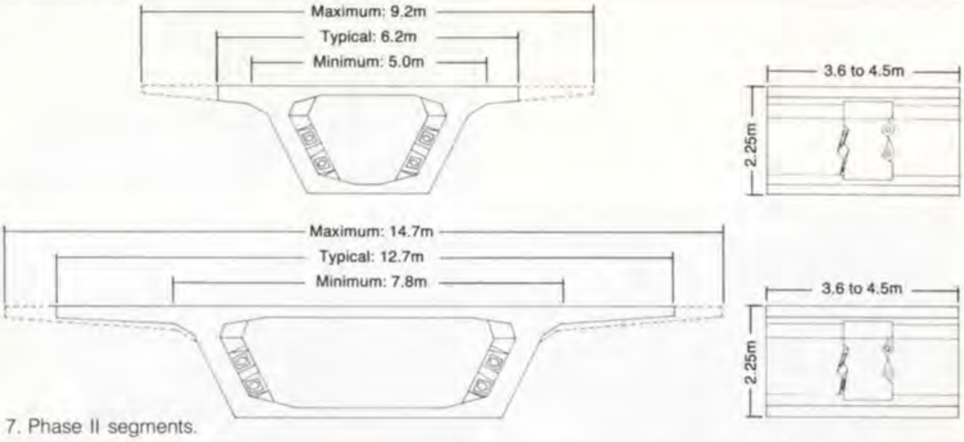
A bored pile requires either a permanent or a temporary steel lining; if the latter, then a nominal reinforcement cage is necessary for the full length of the pile, irrespective of the criteria stated above, to ensure the integrity of the pile during withdrawal of the lining.

This adds to the potential saving in steel quantities if barrettes can be used. Due to our interactive soil-pile design it was only in a very few cases that reinforcement had to be provided in the lower parts of the barrettes. This led to substantial savings in reinforcement.



4 Principal stages in four-day erection cycle of parallel pair of cantilevers

5. Phase II column top.



7. Phase II segments.

The columns

The front elevation of the conforming column was generally maintained, but the side was changed to make room for the equipment required to fix the pier segments to the column during the cantilevering.

The controlled un-hooking by the launching girder of a segment pair would normally ensure that the out-of-balance force would be less than 20 tonnes; however the fixity and the foundations had to be designed for the extreme case of a segment being accidentally dropped.

The deck

Phase II consisted of 27 individual structures separated by expansion joints. From a design point of view we had 18 different bridge decks of varying complexity, from the simple straight bridge along the seafront to the tapering and curved bridge at the ramp bifurcations.

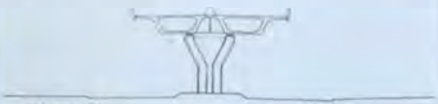
Phase III consisted of 10 four-span bridges. The 20m wide deck was, due to land restrictions, supported at each pier location by a single central column. The alternative deck cross-section consisted of two boxes connected through a 1m in situ stitch, containing the central barrier. At pier locations transverse prestressing was introduced to transfer the web shears to the bearings. There were six different span configurations to design. Fig. 6 shows typical cross-sections along the viaduct.

Phase II: Eastern bifurcation

Phase II: Central section

Phase II: Western bifurcation

Phase II: Ramps



Phase III

6. Typical cross-sections.

The segments

The geometry had to be fixed very early, to allow time for the contractor's formwork design. Casting of the first segment was scheduled in September 1989, and the manufacturing of the casting cells, seven in all, was to be tendered across the border in The Peoples Republic of China.

Apart from the anchorage rib and a decision to have two web thicknesses, 450mm and 500mm, in the large segments, only minor changes were made to the segments as envisaged in the alternative tender design. Fig. 7 shows typical large and small segments for Phase II. Fig. 8 shows the shear keys and the possible duct positions in the end-face of a small segment. The shear keys act to carry the shear across the joint until the epoxy glue applied to the end-faces has polymerized, usually after about two hours.

Due to their weight the pier segments were split in two halves, each 2.1825m long, while the length 'l' of the intermediate segments in a particular span related to the span length 'L' in the following way:

$3.6 < l = (L - 2 \times 2.1825 - \text{Gap})/N < 4.5$
where $N = 7$, 8 or 9 and $\text{Gap} = 0.2\text{m}$
(the in situ closing stitch at midspan).

Analysis and design

Using the in-house BRILO program a grillage model for each structure was built up and loading was applied in the relevant construction stages. Construction loads from the launching girder and other equipment at each stage were supplied by the contractor and taken into account. Stresses were checked at each construction stage and at long term after creep redistribution using the PREPAK program.

The western bifurcation of Phase II was particularly complex. The cross-section was made up of four segments, column positions were restricted due to interference with the ground level roads, and it was not possible to locate a column below each segment. To overcome this, solid diaphragms connecting the columns in the transverse direction were constructed in situ and the precast segments attached to these. These diaphragms, 3m wide, were designed to support the 450 tonne launching girder during the cantilevering of the segments (Fig. 9).

The most critical tasks of the design were to develop the cable profiles and the reinforcement cages for the segments. The contractor's production target for the 2200 segments was 16 months, based on a production cycle of one segment per cell per day for the seven casting cells. In order to achieve this rhythm it was imperative that the segment reinforcement cage, including the cable ducts, was entirely prefabricated, and that anchorages, inserts, lifting holes, openings for drainage gullies, etc., could be installed quickly and without adjustments to the cage after it had been positioned in the casting cell. The transversely stressed diaphragms of Phase III required individual reinforcement drawings at 1:10 scale, to satisfy the contractor that there would be no surprises during production on site.

Drawing production

Arups produced 1200 drawings for Phases II and III during the first eight months of the design. In addition to these, a large number of schedules or so-called catalogues were produced, and it was in fact these, rather than the drawings, that the contractor used for the segment production. Each segment had a set of catalogues giving specific information relevant to the production of that segment. The most important of these catalogues were:

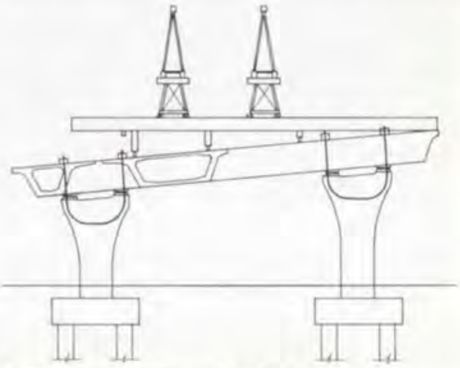
(1) Segment, Reinforcement and Formwork, containing overall geometry data and bending schedules

(2) Prestressing, giving anchorage sizes, duct sizes, profile data for prefabrication of ducts, and cable support shapes

(3) Inserts and Openings, listing all the various hangers, gully openings, access holes, etc., which might be required in a particular segment.

Over 60 000 A4-sized sheets/schedules, each with unique information, were produced for the segment production. These documents were not certified by the checking engineer as he was concerned only with the checking and certification of the drawings.

8. Phase II segment: shear keys and duct positions.



9. Diaphragm at western bifurcation.

CONSTRUCTION

The first of the 300 barrettes was constructed in May 1989 (Fig. 10). The seven precasting cells, containing 600 tonnes of fabricated steel with hydraulically-operated shutters, were installed on site in August 1989, and the 112m long launching girder arrived in September 1989 for assembly and testing on site.

13.

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14. Phase II: February 1990.

Segment production

Fig. 11 shows the layout of the precasting yard. Behind each of the seven casting cells are four jigs where the reinforcement cages were prefabricated. Five of the cells produced intermediate segments and the others pier segments. The batching plant and the storage area for the segments are next to the casting cells.

The most important steps in the 24-hour segment construction sequence are:

(1) Place reinforcement cage for segment 2 in outer shutter of casting cell against segment 1 in counter-mould position
(2) Push in inner shutter
(3) Close end of form with stop-end shutter
(4) Cast segment 2
(5) Remove segment 1 to store, and lift segment 2 into counter-mould position
(6) Survey segment 2 and revise dimensions of segment 3 accordingly
(7) Rotate and tilt segment 2 to suit horizontal and vertical alignment of bridge
(8) Twist casting cell to suit changing superelevation of segment 3 if required.

The segments were lifted out of the casting cells only 11 hours after concrete pouring and without steam curing. Concrete strength at this time was 18 Mpa; and after 28 days: 85 Mpa.

Early strength was measured non-destructively using a maturity method based on temperature readings inside the hardening concrete. The concrete technology was refined by the contractor on recent precast works in France.

The first segment was cast, as planned, in September 1989, and the production rhythm of one segment per cell per day was reached after three months. The last of the 2200 segments was cast in December 1990.

15.

16.

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18.

Deck erection

This began for Phase II in November 1989. The first two spans of the western exit ramp were erected by crane (Fig. 12), giving access for the launching girder onto the bridge (Fig. 13: December 1989). The first deck to be erected by the girder was the bifurcation with the three in situ diaphragms. The girder then moved towards Phase III. The whole of Phase III, 1.4km of dual two-lane carriageway, was erected in three months. Fig. 15 shows the temporary supports required at the single columns of Phase III to allow cantilevering of the two lines of segments.

Fig. 16 shows a pair of segments being positioned. The epoxy glue is applied to their end faces immediately prior to the installation (Fig. 17). The main purpose of the glue is to provide a watertight joint — particularly critical during the grouting of the permanent cable ducts.

Fig. 18 shows the installation of the temporary Dywidag bars during erection: After having completed Phase III in July 1990, the girder travelled back onto Phase II and the erection of the viaduct was completed in April 1991. The contractor could in fact have completed 3-4 months earlier, but due to contractual restrictions could not gain access to the eastern end of the site until February 1991. Route 6 officially opened for traffic on 1 July 1991.

During the erection of Phase II the contractor achieved an erection speed of 72 segments in one week — equivalent to 160m of dual three-lane expressway, or 4000m^2 of bridge deck in one week.

19. Phase II columns with new seawall on the left; Kowloon tower blocks in the background.

20. Nearing completion of Phase III, June 1990; on the right is the partially completed HACTL air cargo terminal, another Arup Hong Kong project.

The project team

In jobs of this type where the detailed design does not begin until after the contract has been let, considerable effort is required to ensure that the design is at least one step ahead of construction. Credit is due to the Arup staff in Hong Kong, particularly the draughting and detailing teams, who worked under great pressure to produce the hundreds of drawings and catalogues which had to be issued on time to satisfy the extremely tight construction programme.

Conclusion

This project provides an excellent example of the benefits which can be gained from co-operation between consulting engineer and contractor in a design-and-construct relationship. In this case, at the time of tendering, the consultant, in the role as designer, was able to assure the contractor that his proposals for an alternative method of construction were both viable and economical. Later, after the award of the contract, the consultant expanded his preliminary design into detailed design with comprehensive construction drawings and was available to assist the contractor in fine-tuning his scheme and in dealing with any unforeseen circumstances.

It is worth emphasizing that although the contractor's bid was competitive it did not offer a utilitarian solution: on the contrary, by virtue of his ingenuity, expertise in construction and organization he was able to satisfy the client's exact requirements with a scheme that was efficient and financially economical.

Credits
Client:
Hong Kong Highways Department
Contractor's designer:
Ove Arup & Partners
Contractors:
Dragages, Bachy Soletanche JV
Photos:
L.M. Lui
Illustrations:
Ajoy Ghose

21. Completed Phase III, July 1991.

Soda ash project, Sua Pan, Botswana

Colin Dittmer
Ernie Hall

Introduction

Soda ash (sodium carbonate) is an important material in the glass, metallurgical, and detergent industries. The 700M Pula (£190M) project recently completed at Sua Pan in Botswana is designed to produce about 300 000 tonnes per annum, approximately 1% of world output and enough to make Southern Africa self-sufficient in its production. In addition, some 650 000 tonnes per annum of common salt (sodium chloride) will be produced as a by-product for use in the food, agricultural, and chemical industries.

The client, Soda Ash Botswana (Pty) Ltd. (SAB), is jointly owned by the Government of Botswana, AECI, and the Anglo American Corporation, and the project represents an important joint venture between the Botswana Government and Southern African industry, technology, and financing. When in full production, it will generate some P120M per annum in foreign exchange for the region.

The plant is located about 180km north-east of Francistown, on a sandy spit of land protruding some 20km into Sua Pan on the north-eastern side of the Makadikgadi Pans complex in north-eastern Botswana. The site is about 8km from Nata, the eastern extremity of another important Arup project, the 300km Nata-Maun road.

The process

The production of soda ash involves extracting brine from an aquifer below the pan surface. The brine is pumped from a wellfield covering over 150km^2 in the northern part of Sua Pan into 20km^2 of solar evaporation ponds on the northern side of the spit, where it is concentrated and common salt deposited and harvested. The remaining liquor is then pumped to the process plant on the spit for the extraction of soda ash.

The plant itself covers an area of 65ha and includes the following:

- A 170 tonnes/hour steam plant
- A CO_2 recovery system
- A 20MW turbo alternator
- Carbonation and crystallization vessels
- A thickener
- Calcining and compacting units
- Salt washing and milling units
- Coal and product handling and storage facilities
- A railway marshalling yard
- Ancillary buildings, i.e. stores, offices, maintenance facilities.

1. Sua Pan, showing scope of soda ash project.

2. The plant across the solar ponds.

Infrastructure development associated with the project includes a 170km rail link to Francistown, a new 40km road to Dukwe, two 40km pipelines, an airport, and a town of 600 houses together with associated infrastructure.

The contract team

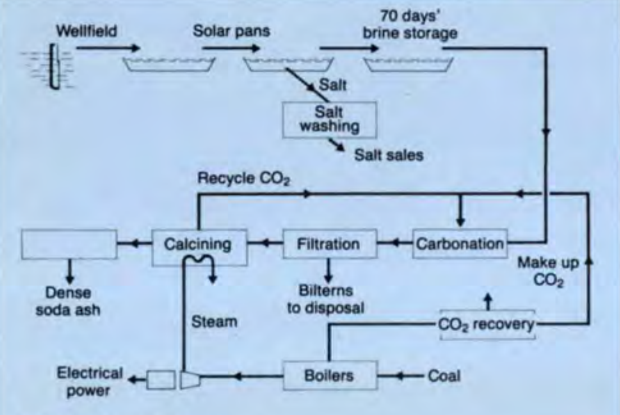
SAB appointed a principal contractor comprising Uhde (Pty) Ltd. and LTA Process Engineering Ltd. to be responsible for the entire engineering and management of the project. The principal contractor in turn appointed Arups as a third member of their team, to undertake the design, documentation and site monitoring for all the civil, structural, building, foundation engineering, and infrastructural aspects.

Uhde, who undertook the overall project management, also appointed Arups' subsidiary, Capital Projects Planning Services (Pty) Ltd. (CPPS), to supply the computer-based project control systems for the whole scheme.

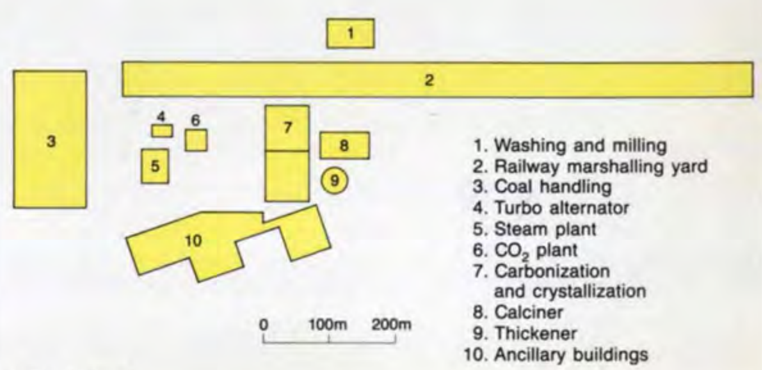
A dedicated project team was thus established, comprising the principal contractor, the Arup team, and a number of client personnel, who were all accommodated in a separate project office. The principal contractor's involvement amounted to nearly 1M man-hours, of which Arups' involvement represented about 160 000, with staff peaking at around 60.

Special features of the project

The remoteness of the site made the work logistically complex, especially because of the initial lack of infrastructure at the site, the travel distances involved, limited construction capacity within the buoyant Botswana construction industry, and controls governing the processing of work permits for expatriate staff. In addition, the programme demanded that engineering and construction of the entire project be completed within 2½ years of the principal contractor's appointment.



3. Process flow diagram.



4. Plant layout.

Arups' involvement: overview

Geotechnical and foundation engineering

- All geotechnical investigation of the plant site, solar ponds and new town, together with detailed foundation design
- All geotechnical investigation and materials assessment for construction of the plant roads, airport runway, and new road to Dukwe
- Geotechnical investigation and materials assessment for establishing a quarry to supply aggregates for construction. The new quarry was, in the end, not established, owing to favourable rates being negotiated with existing quarries in Francistown.
- Geotechnical investigation and foundation recommendations for all houses and facilities at Sowa Town.

Civil engineering and infrastructure

Plant infrastructure

- 65ha of terracing and stormwater drainage
- 6km of plant roads
- 4km of sewerage reticulation
- 7km of railtrack in exchange yard

Wellfield and solar ponds

- Earthwork platforms for wells and electrical substations in wellfield
- 60km of earthwork berms around solar ponds
- Weirs, pumpstations, and electrical substations for solar ponds

External infrastructure

- Airport runway
- Upgrading existing gravel road to Dukwe for construction traffic
- New 40km road to Dukwe
- Two 40km water pipelines
- 32m diameter, 5M litre capacity concrete reservoir
- Sewage treatment works, and water and sewage pumping stations

Structure and buildings

Plant structures

- 30 000m^3 of concrete foundations and structures
- 2500 tonnes of steel plant structures

Ancillary plant buildings

- 10 500m^2 of administration buildings, workshops, stores, substations, and other ancillary plant buildings, including HVAC design

Sowa Town

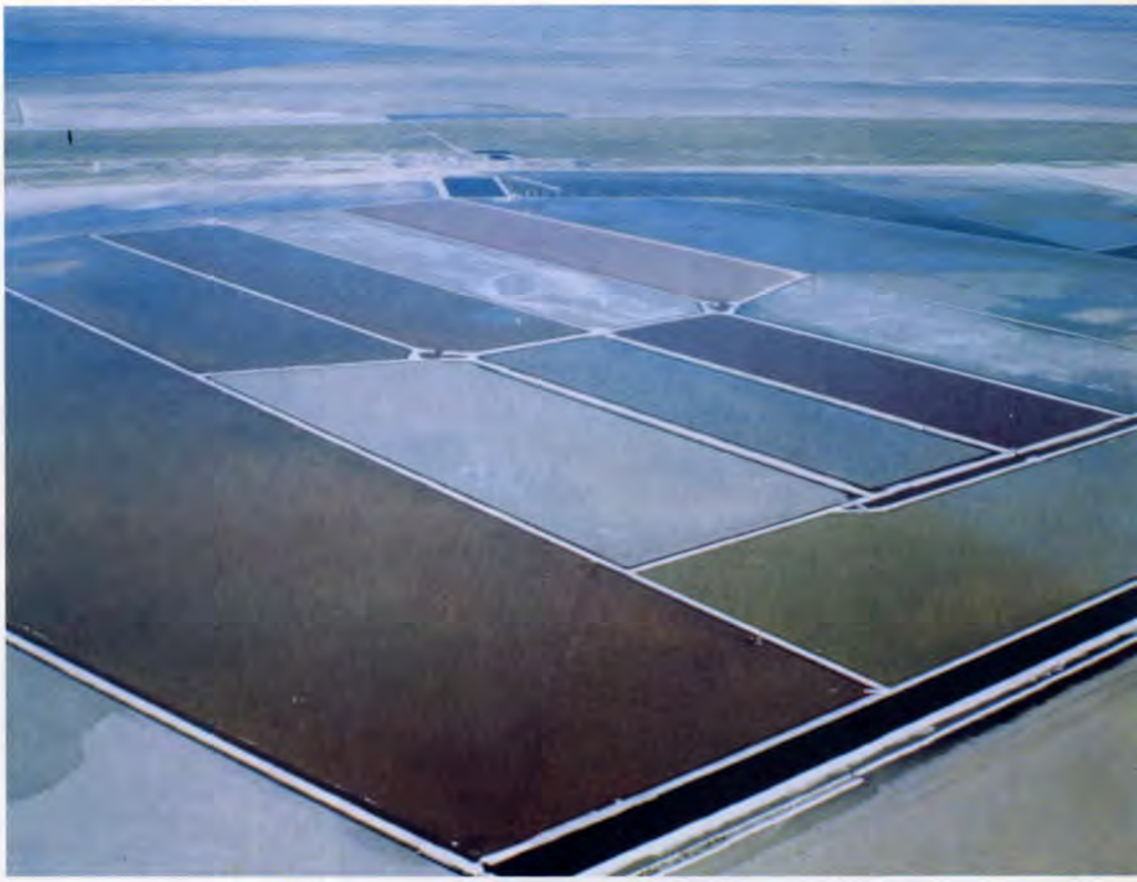
- Foundations for 600 houses
- Shopping centre, school, telephone exchange, social club, and community centre.

On-site monitoring of construction

From the start of construction Arups' resident site staff, established as part of the principal contractor's construction management team, monitored construction of the works in relation to the specifications.

Project management information systems

CPPS provided the principal contractor with the computer-based information systems for time, cost, procurement, and document control for the entire project, as well as staff and hardware to implement the systems for the full duration of design, construction, and commissioning.



5. The solar ponds:
the plant is barely visible in the distance.

6. Solar pond station under construction.

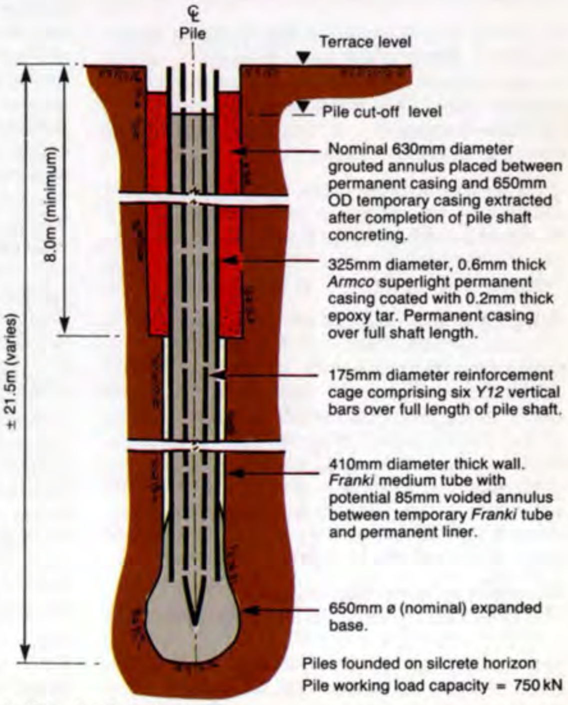
The project's unique features related particularly to construction environment, materials, and geology. Building the wellfield and solar ponds, for example, involved operating and conveying equipment over large distances on the pan — still under water at the commencement of the project, and in which vehicles often got bogged down. Special corrosion problems arising from the aggressive conditions had to be dealt with and available materials used to the best advantage, as in construction of the solar pond bund walls and the new Dukwe road.

Arups identified these key strategic issues at the outset, and proposed and implemented solutions to the infrastructural problems while other major process and mechanical engineering issues were still being resolved. In this way, early and efficient infrastructure construction could proceed, thereby enabling critical early programme dates for items like the access road, water supply, solar pond bund walls, and piled foundations to be achieved. This fast-track approach necessitated accommodating frequent changes to plant and vendor data as the design developed.

Key Arup responsibilities

Geotechnical and foundation engineering

The spit of land on which the plant is located consists of sandy lacustrine deposits up to 5m thick overlying the pan deposits. These are soft silts and sands with cemented horizons, to bedrock at 40m depth. The deposits are unable to support major loads without large settlements, and consequently heavy loads and settlement-sensitive structures had to be supported on piles. Because of the depth to bedrock, advantage was taken of a concretionary horizon up to 18m below surface, on which driven cast in situ piles were founded with expanded bases to reduce contact pressures. The adequacy of this pile type was confirmed by trial testing. The piling was complicated by aggressive ground conditions which necessitated lining with a permanent bitumen-coated steel sheath.



7. Pile detail at plant area.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8. 40m diameter concrete thickener.
9. Crystallization vessels.
10. Impact rolling of plant terrace.
11. 16 500m^2 clear span soda ash store.
12. Calciner.
13. Filtration and compaction building.
14. Cooling water pipe trench.
15. Soda ash rail loading facility.
16. Soda ash bagging and loading facility.
17. A house in Sowa Town.

For initial improvement of the founding conditions the entire plant area, measuring about 1.1km × 0.6km, was levelled and treated with an impact roller. This produced reasonable but variable compaction of the collapsing sands down to about 2m depth.

In order to minimize costs, light buildings and structures not sensitive to settlement were founded on individual earth rafts constructed by removing about 2.5m of potentially collapsing material and replacing it in compacted layers.

Advantage was taken of the early construction of three 10m diameter, 10m high water tanks to measure settlements with different earth raft preparations. The small settlements measured under these tanks confirmed the performance of the sands under relatively light loads after compaction, and enabled soil parameters to be calibrated for prediction of settlements under other structures. Subsequent design and construction of elements of the plant founded on soil rafts confirmed these assumptions.

Durability of concrete structures

The presence of chlorides and sulphates in the pan deposits necessitated careful assessment of the associated aggressive attack on the concrete. Academic advice was sought, and the resulting report reviewed by Arup Research & Development in London.

The solutions adopted varied, depending on whether structures are permanently below or above the water table, or in the most aggressive intermediate zone. Generally the solution involved a combination of good quality dense concrete with high cement content, the use of slagment, cover to reinforcement of up to 75mm and bitumen coating of vulnerable surfaces located in the zone below ground level and the lowest water table.

Civil infrastructure

Early contracts were awarded for upgrading the 40km access road from a point near Dukwe on the main road from Francistown to Nata, for the two 40km pipelines along this road (one for potable water and the other for brackish), and for the surfaced airstrip. The upgraded calcrete access road was used to carry heavy traffic during the construction phase. Towards the end of the project, the final surfaced access road was built, a two-lane facility using local calcrete in the construction layers with a double-seal surfacing. Shoulders were also sealed. Over the first 10km from the plant, particular attention was paid to design and construction techniques, including a bitumen membrane between the sub-base and base courses, in order to minimize the likelihood of surface blistering due to salts migrating upwards from the groundwater.

The 170km railway link from Francistown, which supplies coal for the boiler and conveys the product to the main rail network at Francistown, was designed by others for Botswana Railways. Arups were responsible for the railway exchange yard at the plant, including coal offloading and handling facilities, bulk and bag loading facilities for the salt and soda ash, and rail wagon weighbridges.

Solar evaporation ponds

Establishing the layout for these involved detailed interaction between the civil engineers and process consultants. The 60km of earthwork bund walls around the 20km^2 of ponds were constructed with the available pan materials, and also serve as access roads to weirs, pumpstations, and other equipment on the pan.

Tests had been conducted by others during an earlier pilot project to establish permeability and other parameters, and to establish a proposed form of construction. These concepts had to be developed into a workable solution, and precontract test section was let to prove the proposed method of construction.

With the water table near the pan surface, the procedure involved excavating pan material adjacent to the proposed bund wall, and spreading it along the line of the wall. The operation was programmed to allow as much drying as possible of the soil to take place to improve the compaction potential, although even then the material had to be compacted at well above optimum moisture content. It was nevertheless demonstrated that with suitably chosen equipment, adequate compaction could be achieved along the bund walls within an acceptable construction programme.

It was recognized that certain leakage would take place through the floor of the ponds and through the walls. These were measured in the pilot project and allowed for in the wellfield and solar pond design. With time, a salt floor forms across the salt crystallization ponds which,


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together with algae deposits, reduces leakage and possible damage to the bund walls through wave action.

Brine collection system

The brine wells, pumps, and electrical substations which are situated in the wellfield some 20km from the plant have been constructed on earthwork platforms to raise them above possible floodwaters in the pan. These earthwork platforms were constructed in a similar manner to the solar pond berms, by excavating adjacent pan material and compacting it in layers after allowing time for drying.

Special structures

There are a multitude of concrete and steel structures in the plant, ranging from bases supporting individual plant items to pipe racks and major structures and buildings. The structural design, therefore, needed close interaction with the process, mechanical, and electrical designers, so as to produce reliable civil and structural information to meet urgent construction requirements, within a dynamic design environment. Two structures deserve special comment:

Thickener

The 40m diameter thickener had, for process reasons, to be some 5m above natural ground level; below its floor, access tunnels connect to the central extract pump chamber. A number of alternative forms of construction were investigated. Elevated piled structures in either concrete or steel were considered but would have been costly. Instead, the structure was founded on an excavated and recompacted soil raft and designed to accommodate predicted settlements.

The reinforced concrete drum is supported on a spread footing at just below terrace level. Foundation preparation involved excavating and recompacting material down to 2.5m below ground level. The walls of the structure were designed to allow earth fill to be compacted internally up to the sloping floor of the thickener, which is between 4.5m and 7m above ground level. The thickener was then lined with a flexible membrane to accommodate the corrosive salts in the contained liquid and to provide flexibility to accommodate settlement of the floor. Flexibility has been built into items connecting into the thickener to allow for up to 50mm of settlement. Measurements of settlements on site have confirmed the design parameters adopted and the soundness of the solution.

Dense soda ash store

This major building is 330m long, 50m wide, and 20m high to the roof apex. It accommodates conveyors and sets of rail tracks down each side, on which the stackers and reclaimer run. Between these tracks, a heap of soda ash up to 12m high at the apex is accommodated.

It was recognized that piling under the rail supports along each side of the building to deal with settlements would be extremely costly. Nevertheless, the stacker and reclaimer rails had to be adequately supported to ensure minimal differential settlements. Careful analysis and design of reinforced concrete ground beams on the elastic subgrade showed that differential deflections could be contained within acceptable limits.

The building is therefore founded entirely on spread footings and strip beams. The steel structure is divided into four sections along its length to allow for longitudinal temperature movements; the tubular steel portals at 10m centres are designed as three-pinned arches, and provide a clear span area of 16 500m^2. The building and stacker/reclaimer system was chosen as more cost-effective than conventional concrete silos and conveyors.

Sowa Town

This provides over 600 houses for workers at the plant, together with other facilities and amenities. The houses range from high to low-cost and are being provided by the Botswana Housing Corporation for rental by SAB. The former appointed its own consultants for the town's road and services infrastructure. Arups' work in the Town includes the following:

- Advice on structural and electrical aspects for the houses
- Geotechnical advice relating to all foundations — which are on collapsing sands
- Infrastructure, civil, and structural design of the shopping centre, school, telephone exchange, social club, and community centre
- Design of 32m diameter, 5M litre, reinforced concrete reservoir and pumping station.

Conclusion

The principal contractor was appointed in October 1988, when the basic process engineering for the project commenced; an earlier pilot scheme had been constructed on a smaller scale to evaluate the wellfield, solar ponds, and process. Design and construction of the entire project was completed in the stipulated 2½ years, with the first soda ash coming out of the plant in March 1991. At the peak of construction activity, there were more than 2000 workers employed at this remote site — a logistical problem which necessitated providing extensive accommodation and catering facilities on site, and laying on road and air transport.

In terms of scale, scope of involvement, and ability to contribute to the overall end result, the Botswana soda ash project has represented an important milestone in Arups' participation in this kind of work.

Credits
Client:
Soda Ash Botswana (Pty) Ltd.
Principal contractor:
Uhde (Pty) Ltd./LTA Process Engineering Ltd.
Civil, structural, building, foundation, and infrastructure engineers:
Ove Arup
Photos:
1: Ove Arup; 2, 5, 9: Dave Norman;
6, 10, 14: Ric Bennett; 8, 11, 15, 16: Colin Dittmer;
12, 13, 17: Cliff McMillan.
Illustrations
1, 7: Emőke Baroni; 3,4: Fred English

Communications and Information Technology

10 years communicating

Ove Arup & Partners started to develop communications as a specialist consultancy service in 1981. Since then the group has grown to serve many clients on widely differing projects. Those described here are of two kinds: ones on which communications is the sole service provided by Arups and those where it is one amongst many.

The last 10 years have seen an increasing awareness of the impact communications and information technology (IT) are having on buildings. Few projects or clients are unaffected by changes in the technology which allows people to talk, exchange text, or transmit pictures remotely, with increasing ease. To the problem of designing a building to accommodate many generations of IT system is added the question: what kinds of system should be provided? The Communications and IT Group, located in the Industrial Engineering division, sets out to help solve the first and to answer the second.

Sanctuary Buildings

Iain MacCall

Sanctuary Buildings, a 12-storey office block near Westminster Abbey, is the new head office of the Department of Education and Science (DES) for around 1200 staff, completed in December 1991.

Back in October 1988, the DES invited Arups' Communications & IT Group to review the proposed facilities for the communications infrastructure in Sanctuary Buildings. As a result, extensive changes were proposed, which had a significant impact on the structure and services. Recommendations were implemented, including:

(1) Dual entry points into the building for public network services

(2) Larger central communications and computing rooms with special services requirements

(3) Provision for sub-equipment rooms which act as flexibility nodes and house the communications and IT equipment serving each floor

(4) Various methods to provide IT services to desks

(5) An uninterruptible power supply for IT equipment.

Approximately 850 PC workstations from their old premises, Elizabeth House, near Waterloo Station, and others from smaller offices, were relocated and networked at Sanctuary Buildings. Due to existing investment, the most cost-effective networking solution was a structured Ethernet wiring scheme based upon thick-wire backbones with horizontal thin-wire segments. This provided around 1800 outlets allowing for projected future expansion.

To allow for the predicted data traffic and to give resilience, four bridged backbones were used. Multiport repeaters, with the ability to include local bridges separating individual user groups from the backbones, were installed in each of the 22 sub-equipment rooms. The equipment used had integrated network management facilities so that faults could be diagnosed from a central location.

Remote bridging facilities allow electronic mail services to operate between Elizabeth House and Sanctuary Buildings as well as providing access to the mainframe in the Northern HQ at Darlington.

The Department's voice network was designed to allow PABX management functions including call logging to be controlled from the Darlington office. The network also allows central operator working so that all calls, including those made to the London office, can be answered by the telephonists in Darlington.

The Department operated a video conferencing link between Elizabeth House and Darlington; Arups designed both the new studio and the communications link to Sanctuary Buildings. The voice and data wide area networks were integrated using the drop and insert multiplexers for the main link between Darlington and Sanctuary Buildings.

For the smaller amount of data traffic between Elizabeth House and Sanctuary Buildings, telephone data sets were used to carry data via the inter-PABX links.

The integration of voice, data and image communications on a single high speed link introduced the risk of the two sites being cut off from each other in the event of a single fault. Strategies were evolved to reduce this risk. The multiplexing equipment chosen includes full redundancy and diagnostics so that any failure in this equipment is unlikely to disrupt communications; digital links have been provided into the Government Telephone Network (GTN) run by the Central Computing and Telecommunications Agency (CCTA). In the event of a failure on the dedicated link, voice calls are automatically rerouted via the GTN, to provide a backup facility. This also supports data communications.

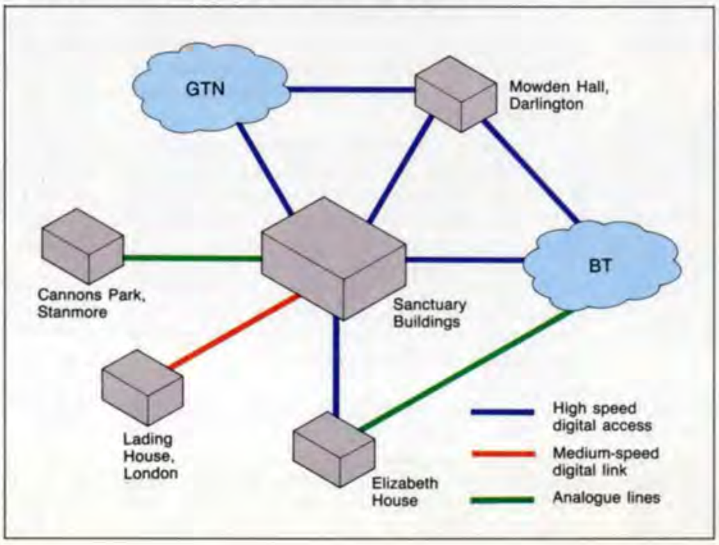
Arups provided significant input to the design process and to the co-ordination of communications and equipment suppliers at all three of the DES major sites, and introduced a new integrated, wide area network.

Credit

Client:
Department of Education and Science

1. Education Secretary using video conference facility. (Photo: British Telecom)

2. DES communications network. (Illustration: Fred English)



Toyota

Emre Serpen

The new Toyota motor manufacturing plant is being established at Burnaston near Derby. When fully operational, it will have a total annual production capacity of 100 000 cars p.a. Shimizu (UK) were responsible for liaison with Toyota Motor Company (TMC) and for design and construction co-ordination. Arups' Communications and IT Group, as part of a large multi-disciplinary design team, including staff from Industrial Engineering, Birmingham office, and other parts of the firm, designed the communications and IT systems that are integral with the plant facilities.

From August 1989 the Group assisted Shimizu with a series of investigations including advice on the legal and regulatory aspects of wide area communications in UK, availability of equipment and systems, capabilities of suppliers, and technical feasibility of specific communications requirements. A plantwide communication strategy was developed, which included:

(i) A broadband system to provide the networking medium for factory automation, building management, and office automation applications

(ii) The voice services exchange (PABX), which also interfaces to Toyota's new engine plant at Shotton, and to other offices and plants in Japan and Europe. The voice cabling system is compliant with Integrated Services Digital Network (ISDN) standards and when fully expanded will comprise 1000 voice outlets.

(iii) A satellite master antenna television system (SMATV), able to receive Japanese programmes broadcast via European satellites.

The use of broadband technology was initially developed for cable television. The frequency spectrum is divided into 6MHz channels, enabling a number of services to run simultaneously on the same cable. Broadband networks are capable of supporting a wide variety of communications protocols, including manufacturing automation protocol (MAP), which enable different computer systems to communicate with each other. The Toyota (UK) broadband system is designed to MAP standards and is based on a 'distributed star' solution, where amplifiers and other active equipment are located at pre-determined 'hub' locations, thus easing system maintenance.

A structured grid system, covering production, office and utility areas, was adopted; the scheme, which initially comprises 400 taps (access points), was designed to expand to 550 taps on demand without necessitating further design modifications. There are 15km of 20mm cable, over 20 trunk and 60 distribution amplifiers, and a comprehensive status monitoring system. In order to enhance the reliability of the network, a dual trunk system is provided where alternate rows of taps are fed from each trunk cable and all trunk amplifiers are provided with active standby modules.

The Group also had a significant input in the tender process, both with interviews and technical appraisal, and this technical co-ordination role continued throughout the contract. The installation of communications and IT systems is complete, and commissioning is expected in 1992.

Credit
Client:
Shimizu (UK) Ltd.

3. Toyota broadband installation. (Photo: Ove Arup & Partners)

4. The Toyota factory, October 1991. (Photo: Jefferson Air Photo)

LFB tower; desk study for alternatives

Bill Southwood

Like all emergency services, the London Fire Brigade (LFB) depends heavily on mobile radio to control its operations. Each fire engine and ancillary vehicle must be in contact at all times by a radio system which is reliable, robust and available.

The capital is served by base stations on Hampstead Heath plus three others around the edge of the Greater London area. The Hampstead site had been the subject of numerous planning appeals, and the temporary tower at Queen Mary's Hospital therefore had a limited life. The London Fire and Civil Defence Authority (LFCDA) called tenders for the design of a 63m high tower on a new site, at that stage undefined, on the Heath. Ove Arup & Partners were successful, with the support of Arup Associates, in being appointed for this project.

At the same time, the Communications and IT Group proposed that the Fire Brigade should look into alternatives to Hampstead as the site for the tower, because any planned structure in the area was likely to be opposed. An independent study could therefore have two outcomes, both beneficial: it might identify an alternative site less likely to result in a public enquiry; on the other hand, if it concluded that there was no practical alternative, this would be useful to the Authority in arguing the case for the new tower.

The need for Hampstead

Hampstead Heath is particularly well-located for a radio base station serving Greater London. It is central, with clear lines of sight through 360° for a considerable distance. It is high enough to clear obstacles, but not so high that it would interfere with other radio services using the same frequencies in the UK and indeed elsewhere in Europe. The Fire Brigade's other stations had been selected to fill in areas not well-covered by Hampstead but which could not, by themselves, cover Central London.

The study therefore concentrated on two aspects: the availability of a site which could replace Hampstead, and the likelihood that emerging technologies might radically change the communications needs of the Fire Service.

Alternative sites

As one would expect, given the sensitivity of the Hampstead Heath area, the fire service had investigated many possible sites. These had included the Telecom Tower, the National Westminster building, Goldfinger's Trellick tower near Westway, Alexandra Palace, and many others. Each had drawbacks: in many cases the height was unsuitable, too high being as bad as not high enough. Sight-lines were not generally as good as from the Heath, which itself forms an obstruction to signals from other base stations. Few could accommodate the number and range of antennae needed by the fire service, nor the radio equipment itself. Availability of reliable power was a key consideration, as was access for maintenance.

Peter Keogh

There was an additional complication: the international body responsible for controlling the radio spectrum, in trying to meet the burgeoning demand for mobile services, had squeezed the frequencies available to the LFCDA. Whereas previously a slightly inferior site might have provided acceptable service, the narrower frequency bands meant that any degradation would be reflected in poorer service. The study therefore concluded that, with the technologies currently in use, no suitable alternative existed.

Technological change

The last 10 years saw major changes in the technology of mobile radio: cellular had boomed, satellite mobile services such as the International Maritime Satellite (INMARSAT) system had matured, and a new technique known as trunked mobile radio had been developed to give better use of the available radio spectrum.

The special needs of the Fire Brigade included all units being in communication with the base and each other at all times. Additionally, no situation where traffic from other sources might interfere with emergency calls could be tolerated. These two factors effectively ruled out terrestrial radio technology — satellite service offered the tempting alternative of eliminating any radio base station on the ground. However, with a satellite 'base station' located 36 000km above the equator, signals are very weak, and need a clear line of sight to the vehicle. This does not exist at street level in the city, so satellite was eliminated as well.

The desk study therefore provided conclusive support to the case for a new station on Hampstead Heath. In the event, the Arup design for a site near the St. Columba Hospital gained planning approval without the need for a public enquiry, and the new 63m guyed mast was erected during October 1991.

Credit
Client:
London Fire and Civil Defence Authority

Hewlett-Packard, Bracknell

Peter Keogh

Hewlett-Packard are famous for computers, test instruments and, among the engineering fraternity, for calculators that refuse to die (long after HP have brought out devices which are smaller, faster, cheaper, better, etc.). They had several offices around Berkshire and wanted to consolidate into a new UK HQ, aspiring to a 'new standard' in building design. HP acquired a large piece of land at Amen Corner near Bracknell and commenced work in 1988 for the first two of the five buildings included in the master plan. Ove Arup & Partners' Manchester office were responsible for the building services design, and the Communications and IT Group invited to assist with the project.

The building was to be the major computer and communications node for the UK. About 1200 staff, in a largely open plan environment, needed to have a highly adaptable communications infrastructure to cater for the many changes to departmental requirements and locations, as HP responds flexibly to industry demands.

The wide area network and internal communications for the company had been based on Case DCX systems giving access to data files and users across the UK, to the USA, and to some European countries. In 1988, HP were in the process of changing their internal communications from the point-to-point serial RS232 system, running at speeds up to 9600 bits/sec., to the high-speed bus IEEE 802.3 system (commonly referred to as Ethernet) running at 10M bits/sec. These new networks now allow for sophisticated management where fault conditions at remote offices like Manchester can be identified. Faulty ports or equipment can be disconnected from the network while they await the arrival of support staff to swop out or amend the defective parts. The scheme for the data cabling needed to accommodate both these networking systems.

The cabling for both voice and data was based on AT&T Premises Distribution Scheme (PDS as it was then, now referred to as SYSTIMAX), configured into a structured wiring scheme. On the floors, radial cables out from a central equipment room on each level ran to grid outlet points (GOP) under the raised floor. Service to the desks was via a drop cable connecting GOP to desk surface, passing through the raised floor via a grometted opening. Compared with the traditional floor box, this proved to be a remarkably cost-effective method of physical cable management, at under 10% of comparable cost.

The building data backbone cabling was thick wire 802.3 cabling enhanced by 125/62.5μ multimode fibre optic cables to give resilience in the face of future developments in communications, particularly with the up-coming Fibre Distributed Data Interface protocol (FDDI).

The site was essentially a campus development and a system of external ducts had to be devised to serve the five buildings. Factors like cable pulling lengths, bend radii, etc., had to be considered; significant costs were involved and it was worth spending time to get it right. The final scheme was an arrangement which allowed for the ring circuit implementation of FDDI but was also sensitive to the needs of two only of the buildings to be masters for communications, each serving a number of other buildings. In 1990, the second building of the master plan was completed, along with the interconnecting external and internal copper and fibre optic cable, forming an integrated network.

The buildings have now been in use for some time and the systems have stood the test of time. The client has been able to reduce his 'churn' costs dramatically; the costs for communication installation when desks move has been reduced by approximately a factor of 10. Whole departments can now be relocated within a day with continuity of service assured. A successful design, implemented.

Credit

Client:
Hewlett-Packard Ltd.

6. Patching in Hewlett-Packard's sub-equipment room.
(Photo: Ove Arup & Partners)

7. Hewlett-Packard office area.
(Photo: Peter Mackinven)

Cellnet, Slough

Jim Read

Cellular radio was one of the communications success stories of the 1980s. Launched in 1985 by two companies — Cellnet and Racal Vodafone — its growth outstripped the most optimistic predictions. In 1989 it became clear to Cellnet that a new headquarters was needed, and they chose a building opposite Slough British Rail Station. Ove Arup & Partners were appointed to design and implement communications and IT systems within the building.

Cellnet and cellular radio

Cellnet is jointly owned in a 60/40 split by British Telecom and Securicor respectively. Its network covers 97% of the UK population from the Shetlands and Orkneys to the Channel Islands. Radio base stations provide coverage in both urban and rural areas, the UK being divided into a large number of 'cells'. In urban areas cells are as close together as 500m, whilst in sparsely populated regions the spacing may be as large as 20km. By early 1991 there were over 750 Cellnet cells in the UK.

Frequencies in the 900MHz band are re-used over and over again as the cellular telephone automatically selects the base station with the strongest signal. Each base station is linked to an electronic mobile exchange (EMX) which controls the call, and arranges for the 'hand-off' from one cell to the next as the mobile moves around within the service area. Control of the total network depends critically on reliable links between the EMXs.

Faced with an explosive demand for its services, especially in major cities and motorway routes, Cellnet embarked on a major expansion programme in the late 1980s. This resulted in a threefold increase in capacity from 10 000 simultaneous telephone conversations in January 1990 to 30 000 in March 1991. Such a growth in demand placed the organization under great pressure, and required much innovation to find novel ways to use the radio frequencies available. One result was the need for a new headquarters building to house not only the organization, but also a new Network Management Centre (NMC). This accommodates the facilities to monitor the entire UK network for traffic demands, system performance and fault conditions, enabling any required corrective action to be taken immediately, at remote locations, often before service to the customer is affected.

Slough building

As a communications organization itself, Cellnet needed its own to be of the highest quality. The building had therefore to be fitted out both with links to their other sites and a flexible internal infrastructure to cope with rapid changes. Also the project needed to be completed very quickly, with the first groups moving in within four months of our being appointed,

8. Cellnet network management centre. (Photo: Cellnet)

The first task was to produce an outline communications strategy. Each operating group of Cellnet was considered, and staff from technician to managing director interviewed. This established the communications needs and priorities for the building, with one need emerging clearly; maximum adaptability. Having started work in November 1989, the report was presented to Cellnet management before Christmas, and formed the basis for the design and implementation stages.

Communications systems

The communications design had to accommodate changes expected right up to the date for the move. An infrastructure of cabling was provided which would allow almost any grouping of departments and layout of furniture to be adopted. The PABX (telephone system) had to allow direct dialling inwards (DDI) and the ability to log costs and traffic statistics.

Having grown so rapidly, Cellnet had a wide range of computer systems, models, and uses; some were networked together, others connected to mainframes which would not move, and the remainder had to be replaced. Another objective was therefore to develop a strategy to allow all machines in the new building to work with one another and with remote computers. This included systems as diverse as billing, personnel and management information.

As a communications carrier, Cellnet needs to cater for a large number of general enquiries and any complaints that arise. An efficient means had to be found for handling such calls. An Automatic Call Distribution (ACD) system was provided to allow a flexible approach with the shortest response time to these calls. Finally the communications for the NMC had to be integrated with the voice and data communications for the rest of the building.

Implementation

Tenders were called and contracts placed with British Telecom for the telephone system and network services. Voice and data cabling was provided by VDU Installations, with data networking equipment and software by Datarange. Work commenced on site early in 1990, and the groups moved in between March and June that year. The systems provided have been subjected to many generations of moves and changes since then, and provide Cellnet with a facility which matches the dynamism of the organization itself.

Credit

Client:

Cellnet Ltd.

Hambros Bank

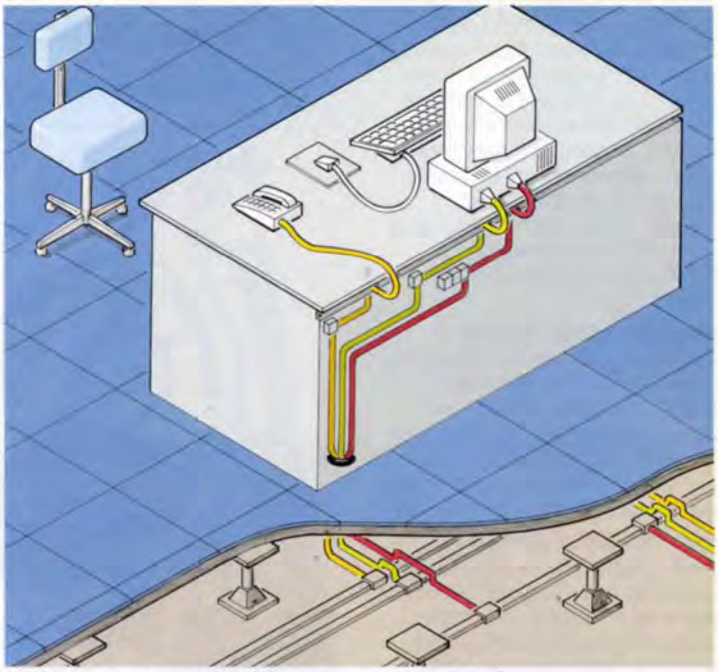
Sam Shemie

Hambros is one of the large City merchant banks, with other offices in Pall Mall and Brentwood, and a number of subsidiary companies offering a wide range of financial services to clients.

Hambros' new building at 41 Tower Hill is located in a prestigious position overlooking the Tower of London and Tower Bridge. It consists of nine floors plus basement, each approximately 2500m^2 with a 180m^2 internal atrium built into the centre from the third floor upwards. The project was carried out in conjunction with Arups' Building Engineering Group who undertook the services design.

When Hambros decided to move, they used this opportunity to review their communications, dealing and IT systems. Voice communications include a networked telephone system as the backbone for the Bank's external communications. The dealers have a dealerphone system, which provides them with direct communications channels to other City institutions, as well as an intercom system for their own open channel voice communications.

Each dealer position can receive a vast range of financial data routed via a complex switching system, thereby providing a comprehensive range of formatted data with optimized access times. The system also provides access to in-house computing facilities.



9. Cabling to the desk, Hambros Bank. (Illustration: Nigel Whale)

10. Hambros dealing area. (Photo: Peter Mackinven)

One of our first tasks was to assess and define the impact of communications and IT on the space and services requirements in the building. The requirements for computer rooms and subequipment rooms, risers, vertical and horizontal tray distribution were defined; two subequipment rooms per floor were required to house the patching frames and the data networking hardware serving the users on that floor.

Given the frequent internal moves and changes within the Bank, Hambros needed a highly adaptable system. Voice and data distribution was based on a modular subfloor grid system with outlets terminated on the slab. Drop cables were used to deliver the services from the subfloor system directly to the furniture via 125mm grommets. Use of floor boxes was limited, resulting, as on other projects, in significant cost savings while maintaining optimum flexibility.

The dealer room had similar requirements; provision was made for 210 dealer desks, with all cables terminating on a module fixed to the raised floor within the desk housing unit. It is interesting to note that Hambros made their own dealing desks in-house — a cost-effective, tailor-made product.

Hambros had a range of mainframe computers acquired over the years by the various line divisions. A modular system was the basis for distribution of data cabling, enabling the Bank to connect to a variety of host machines. It also enables them to use the same system for local area networks like Ethernet and Token Ring.

The migration of staff into the new building had to be planned in great detail, with most communications and dealing systems commissioned prior to moving in. Due to the complexity of these, the main staff move had to take place during the 1988 August Bank Holiday. Arups' input to the planning and control of the related information made a significant contribution to the successful move to the new building. On day one, all systems were reported fully in action and business continued, uninterrupted.

Credit

Client:

Hambros Bank Ltd.

Welbeck: economics and finance

Jim Nyhan   Jonathan Mitchell

Introduction

Arups' long-standing involvement with the Welbeck Reclamation Landfill Project at Wakefield, West Yorkshire, started with a study by Arup Transportation for the DoE into designing an evaluative framework to improve disposal methods for colliery spoil in 1984. Welbeck was one of several case studies in the three-year investigation[1]; subsequent Arup work assessed the environmental implications of alternative rail off-loading points.

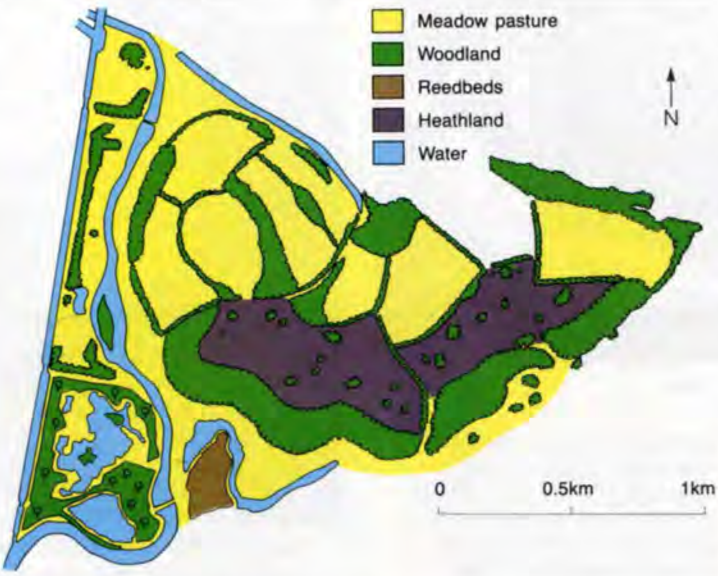
Evolution of the Project

The Welbeck site, some 325ha at the outskirts of the town, had been subject to sporadic but extensive sand and gravel working, deep mine and open cast coal extraction, and the unco-ordinated disposal of both colliery spoil and pulverized fuel ash.

In the mid-1980s, Wakefield Metropolitan District Council (WMDC) were becoming increasingly concerned about the imbalance between the scale of derelict land in the District, and the limited funds available for reclamation. The Welbeck site was a particular concern as it would have absorbed about 10 years' allocation of the entire District's Derelict Land Grant to restore. At the same time, as environmental regulations became more rigorous, the joint waste management authorities in West Yorkshire were finding that waste void space was becoming increasingly scarce and expensive to provide.

The Welbeck Project was born from the far-sighted idea that, through selling waste void space on the site in cells within a landform built from spoil generated by local collieries, it was possible to finance the restoration of the area and return it to public open space (Fig. 1). It is an imaginative local authority response to two seemingly separate problems; mineral workings dereliction, and scarce facilities for waste and colliery spoil disposal.

Initially, about 7Mm^3 of spoil was to be imported from the nearby Sharlston Coalfield to create two artificial hills either side of the River Calder, which bisects the site; these would enclose 7Mm^3 of waste void space. This is now referred to as the 'limited' scheme. When it became clear that the new Selby Coalfield, 25km away, would be generating an unexpected 1Mm^3 of spoil a year, the potential for a much more ambitious scheme emerged. By diverting the River, a single larger hill could be created. Known as the 'full' scheme, this alternative will have a total capacity of about 35Mm^3 of spoil and waste void space. As well as the intake from Sharlston, about 14Mm^3 of colliery spoil will be imported from Selby onto the Welbeck site, allowing the construction of larger waste disposal cells to accommodate about 14Mm^3 of waste. Fig. 2 illustrates the differences in both spoil and waste void space provided by the two alternative schemes.



1

Analysis

The land-take for the two alternative schemes is almost identical, but the major procedural difference is that the river diversion needs Parliamentary approval through a Private Bill. As a result of Arups' earlier involvement, the Project Manager of Welbeck asked Arup Economics & Planning to carry out an economic and financial review of the proposals, with the aim of contributing to a viability assessment for a House of Lords Select Committee of the proposed diversion of the Calder. The review was to be completed in close collaboration with the client, WMDC, and their expert witness, Professor Anthony Neuberger of the London Business School. The issues of environmental impact had already been resolved to the client's satisfaction.

Anticipated costs and phasing of capital and operational expenditure for the Project were obtained from WMDC and the West Yorkshire Waste Management Joint Committee (WYWMJC), who are developing it as a joint venture. Incomes from waste and colliery spoil intake were estimated by reference to financial arrangements with British Coal relating to the two coalfields' disposing spoil on the site, and by accounting for the investment of the waste management authorities as commensurate returns in the form of void space provision for waste. Expenditure and income data for both joint venture partners were consolidated to provide a complete cash flow projection for the alternative schemes, and discounted cash flow techniques then applied to examine the fundamental economic viability of each scheme.

Their viability was also examined with reference to the current cost of obtaining waste void space. To assess economic efficiency of the full scheme, the analysis isolated the extra expenditure and income resulting from the provision of its additional, or 'incremental', 7Mm^3 of waste void space.

The financial analysis examined the cash flows for each option for the WMDC and WYWMJC separately to ensure that, irrespective of the basic economic viability of the schemes, each had the resources necessary to finance the Project.

Results

Both schemes were found to provide void waste space at costs lower than current market rates and to generate reasonable economic rates of return. Using a 7% discount rate, it was found that the incremental £15M + cost of the full scheme (mainly due to the diversion of the River Calder), was more than offset by the income associated with the increased void space made possible by higher spoil intake from Selby. The unit cost of providing each m^3 of waste space, the 'implicit cost of waste', was found to be about 30% lower for the full than the limited scheme. The economies of scale derived from the larger scheme are apparent in Fig. 3.

The sensitivity of the project to cost overruns on the river diversion for the full scheme and the absence of future grant receipts was low. Its economic viability is sensitive only to the availability of spoil material early in the Project's life to create the waste void space. Analysis of the financing requirements demonstrated that both schemes could be financed by each of the public authorities.

Conclusions

The review demonstrated that while both are economically viable, and meet environmental objectives, the full scheme offers economies of scale which make it the more attractive option, as well as providing both additional security for waste disposal and a solution to the spoil disposal needs of the Selby colliery. The review clearly demonstrated its superiority.

The review was carried out to a demanding schedule. The economic and financial analysis of the Welbeck Project strongly supports the client's case, and the value of the work seems to have been greatly appreciated.

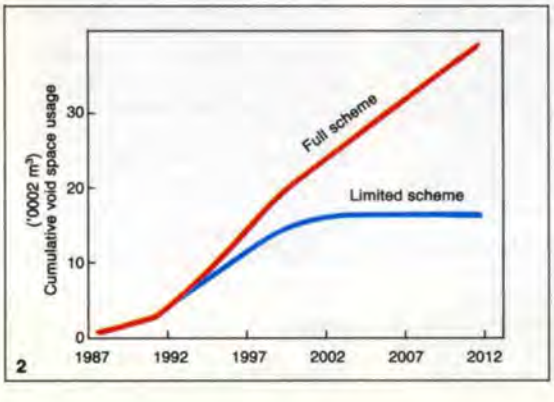
Reference

(1) NOYCE, M. The disposal of colliery spoil. *The Arup Journal, 22*(2), pp.6-7, Summer 1987.

Credits

Client:
Wakefield Metropolitan District Council
Consultants:
Arup Economics & Planning
Illustrations:
Fred English

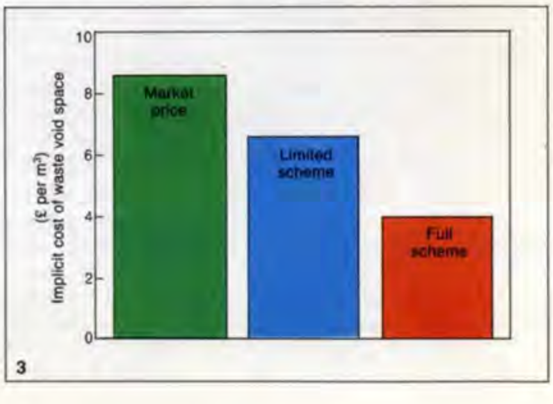
The contents of this article do not necessarily reflect the views of either the client or the expert witness.



1. Top: The final landscape (WMDC, November 1991).

2. Left: Phasing of void space usage for both schemes (WYWMJC, June 1991).

3. Right: Comparison of implicit cost of waste void space (WYWMJC and AEP, 1991 prices, discounted at 7% per annum).



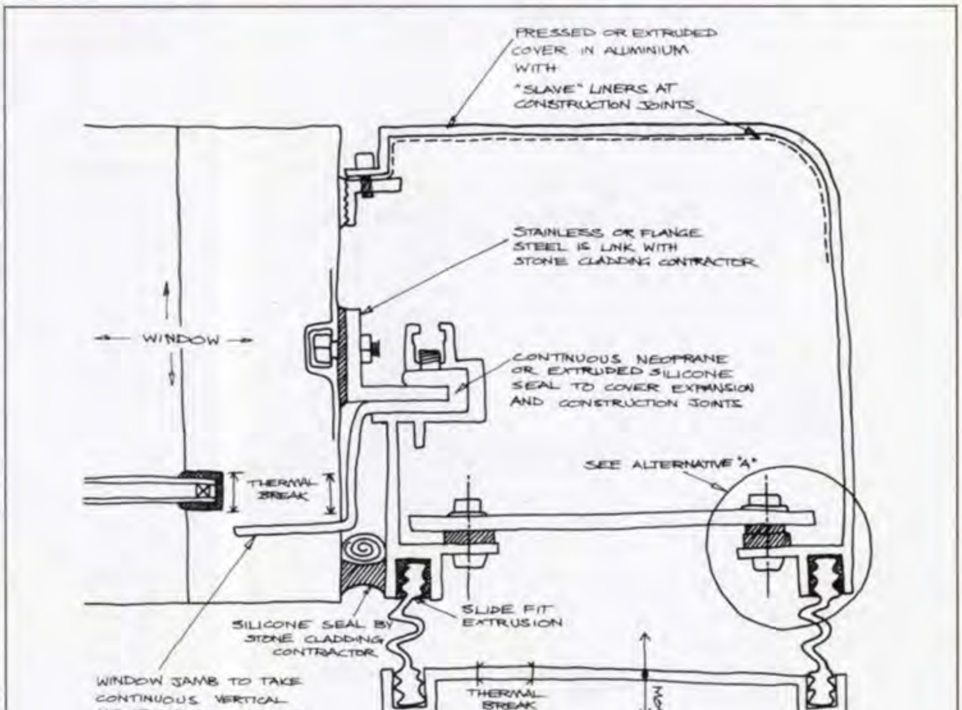
Fabric engineering: The Lee House experience

Architect: Terry Farrell & Co.

John Pilkington
Neil Noble
David Anderson

1. Detail of highly articulated facade, showing elements of stone, glass, and metal. (Photo: David Anderson)

2. Typical technical cartoon produced to assist architects.



In the beginning

The term 'building fabric' is taken to cover all facets of building construction, from internal non-structural elements such as walls and screeds to external walls and roofs. With the move away from craft-based techniques to industrialized system technology for constructing external façades, it is this element of the building which will benefit from greater engineering design input. The range of technologies available for use on building façades is now more diverse than ever. An engineering approach is required to integrate these diverse technologies into the overall building envelope design, an approach that has been called 'fabric engineering'. Building fabric engineers as members of the engineering design team should provide support to the architect by making a contribution to all the technical design functions for the appropriate elements of the building envelope.

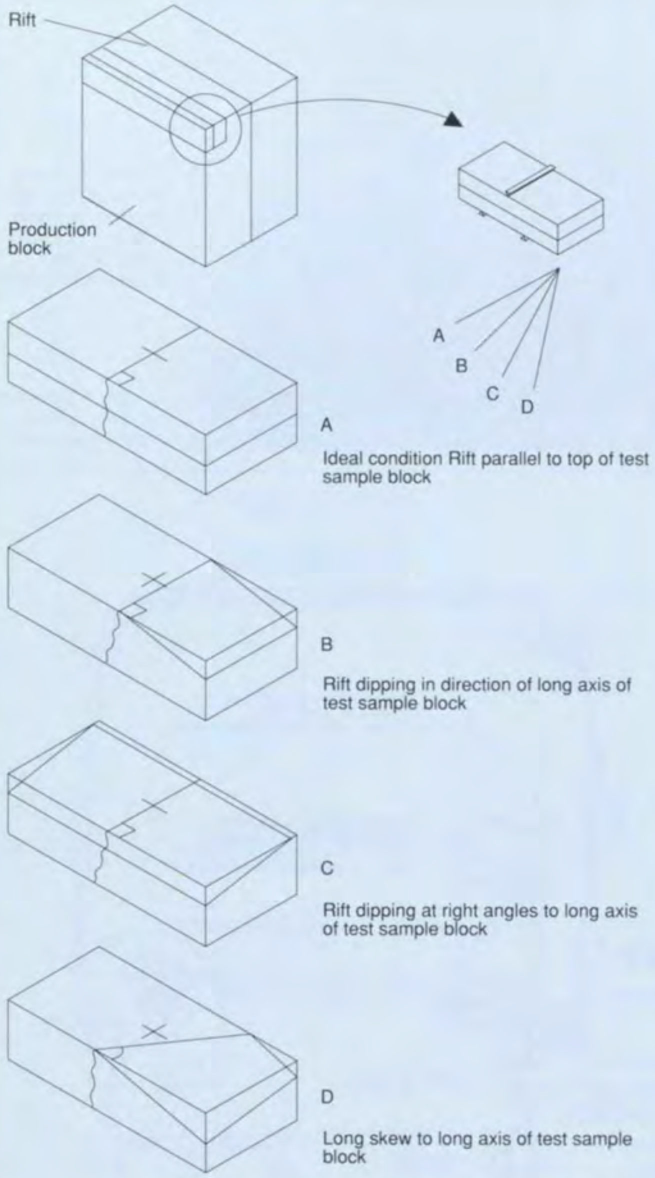
The redevelopment of Lee House was conceived late in 1985 as a response to a difficult development opportunity, the replacement of a '60s tower block by a new building capable of accommodating the most discerning of financial and professional organizations. The 57 000m^2 building for MEPC is constructed partly on the site of the old Lee House and partly as an air rights structure across the intersection of Wood Street with London Wall, in the City of London. The architect, Terry Farrell & Co. (TFC) envisaged a highly articulated façade of stone, metal and glass (Fig. 1) and early in 1986 began discussions on the possibility of Arups providing technical advice on the design of these elements. This was the catalyst needed to get fabric engineering established. By mid-1987 the scope of Arups' fabric engineering duties had been agreed. A team was established in Building Engineering Group 8 (now J), with members of Arup R&D providing specialist input where necessary; external consultants were employed where appropriate to advise on particular aspects of fabric engineering, e.g. façade maintenance equipment.

The Arup role

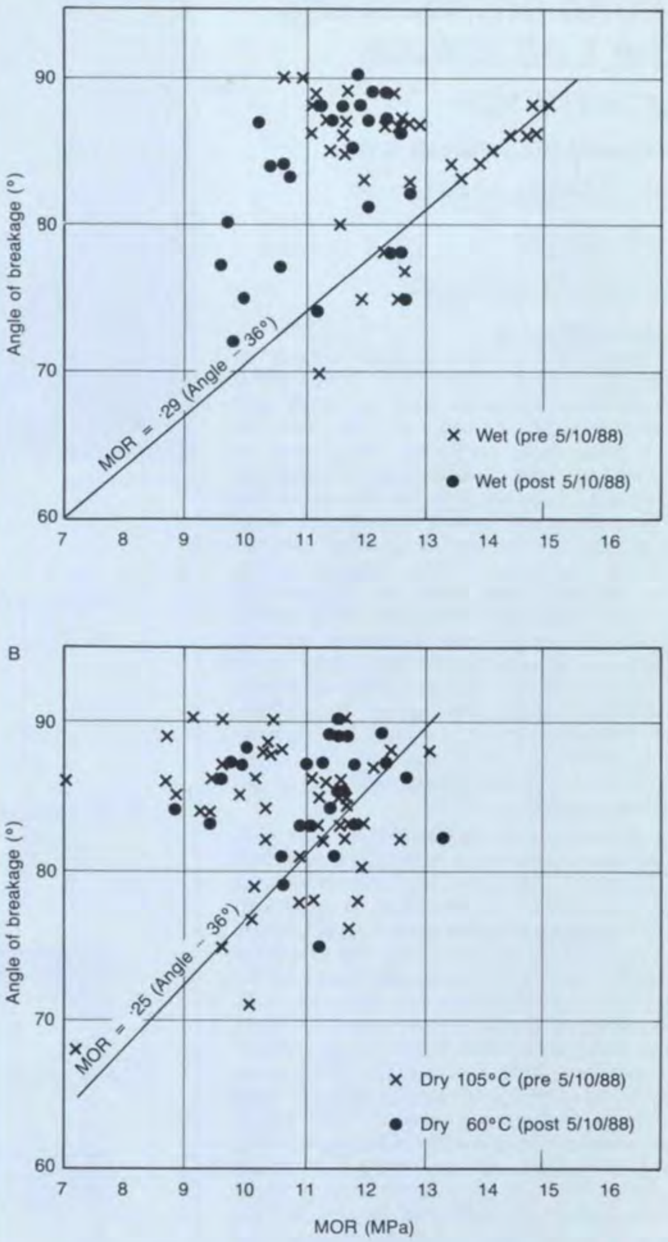
The team provided technical support and advice to the architect on the following building envelope elements:

- Waterproofing for basements, ground works, flat roofs and terraces
- A panelized system of thin granite slabs supported on steel trusses
- Metal and glass curtain walls including some planar glazing
- Special metal claddings to soffits, transfer structures and structural wind bracing
- Traditional hand-fixed granite to lower levels of the building
- Retail, walkway and entrance screens and doors at low level
- Brick and blockwork to low level housing and offices in the west wing
- Windows and curtain walling to low level housing and offices in the west wing
- Façade cleaning equipment
- Plant-room enclosures and feature boxes
- Vault roofs
- Secondary steelwork for vault roofs, planar glazing for four-storey atria, and glazing for four-storey atria.

The team produced many drawings but not in the recognized sense of the word. Rather, the architect was helped to understand the technical performance requirements of the building envelope by technical 'cartoons' of junctions, interfaces and details (Fig. 2) to assist him in the development of his own drawings. These cartoons addressed the performance of the envelope, i.e. air and water penetration, condensation, corrosion, and fire protection, as well as strength, support, movement, and lack of fit. They also helped with the writing of appropriate performance specifications, and when assessing whether tendered design proposals from hopeful sub-contractors were likely to meet the performance requirements.



3. Rift orientation,
controlling angle of breakage and distance from midpoint.



4. MOR values versus angle of breakage.

The few 'proper' drawings produced included elevations of the building showing anticipated movements such as foundation settlements, sway due to wind, movements from transfer structures, and axial shortening of columns and the effects of these on the cladding and roofs. Drawings were also produced of test specimens for full-scale testing of windows and walls, including typical wall features (gutters, corners, recesses, parapets, movement joints, etc.), assembled together to allow various details in the wall system to be tested for strength (serviceability and safety), water penetration, and air permeability.

Once the architect had developed his drawings from the technical cartoon stage, the Arup team carried out further technical audits on these drawings. This included a co-ordinating role with other engineering disciplines.

Technical performance specifications were written, together with specifications for testing to establish compliance with these performance requirements, for 19 separate cladding packages. Some were standard Arup specifications such as for brick and block, but the majority were brand-new.

Many visits were made to potential cladding contractors to establish their resources and design and manufacturing capability, and reports prepared for the architect and client.

5. Glazed facade, with the 1960s' Royex House, London Wall, in the background. (Photo: David Anderson)

After contract award on all cladding sub-contracts, the most time was spent assisting the sub-contractors during their design development process, confirming with them that they understood the requirements of the specification, and reviewing their design drawings.

The quality of the drawn information produced by the sub-contractors caused major difficulties. In many cases they were found to be so poor that *every* drawing had to be reviewed two or three times. On one cladding package alone this resulted in 1600 drawings having to be looked at, instead of the anticipated 50 or 60.

Various tests were observed, from simple pull-out tests on granite fixings and trial installations of wet seals to major weathering and structural tests on full-size specimens. Notes on the tests were written for the architect and client and testing house reports on these tests were reviewed.

The fabric engineering team realised early in the erection process that Arups' structural, mechanical and electrical resident engineers were not qualified to be 'fabric resident engineers', and that there were not sufficient staff to put appropriately qualified members of the fabric team on site. With the architect's and client's agreement, the team instigated a system of inspecting specific areas of each particular type of cladding to set quality standards. These inspections frequently took place in stages so that each element of the construction could be reviewed.

Some interesting results

Granite

The specification for the procurement of the granite was drafted by Arup Facade Engineering in Australia and was developed out of experiences on Grosvenor Place, Sydney. Various strength and durability criteria were specified including density, absorption, compressive strength and modulus of rupture (MOR), all tested to American ASTM codes (there are no British codes). MOR is established from bending tests, carried out on samples cut parallel to the cleavage line or rift, and on samples cut perpendicular to the rift. Results were very variable, with quite a few falling below the specified minimum valves of 10.3MPa. An inspection of the test specimens at the testing laboratory established that the actual position of the rift in relation to the faces of the test specimen fundamentally affected the results (Fig. 3).

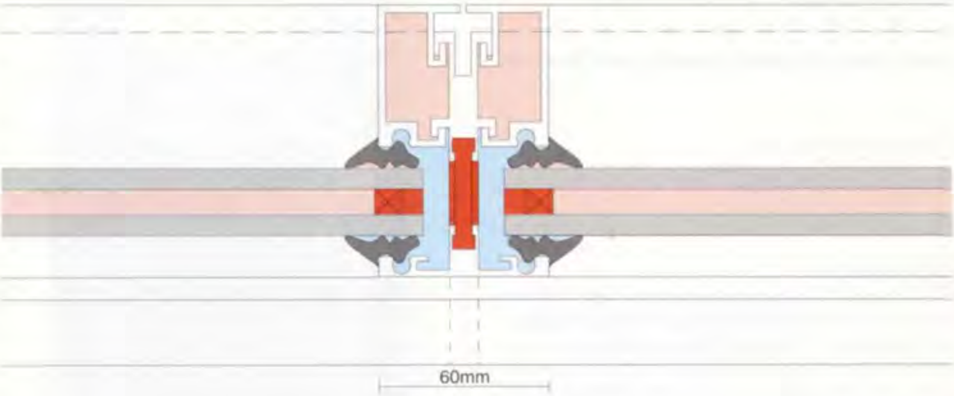
The closer the rift plane was to the orientation of the faces of the test specimen, the higher the MOR values (Fig. 4 shows MOR values well above the specified minimum and close to the quoted value of 13 + MPa given in the supplier's trade literature). Hence the need to establish that the test specimen is cut correctly.

Window mullions

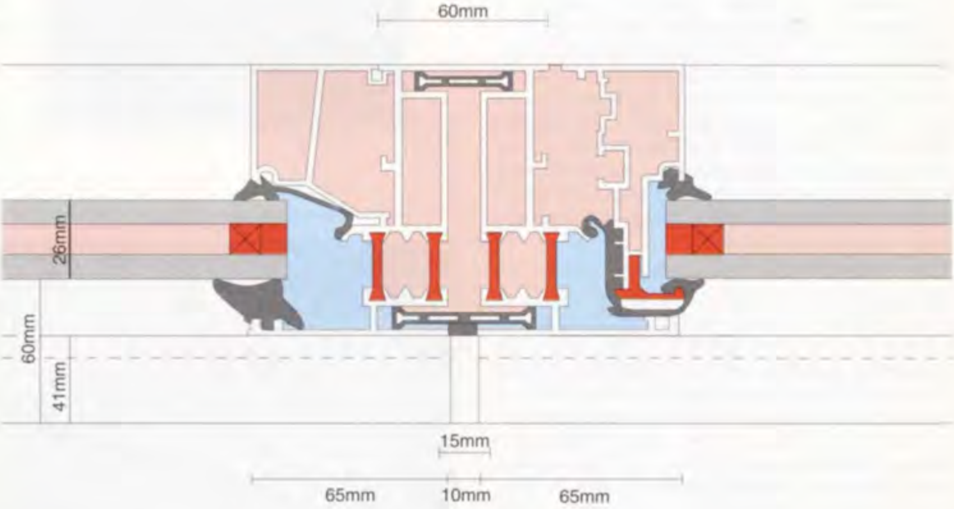
A simple before-and-after comparison can be used to show typical results of fabric engineering work. Fig. 6 illustrates what the architect actually wanted to see. By the time the team had discussed movements, tolerances, support conditions for the glass, drainage, and what happens at opening windows, it was acknowledged that the original architectural concept needed to be modified to that shown in Fig. 7 in order to achieve all the performance requirements. This is a good example of an initiative approach being modified by engineering input to give an appropriate design solution.

Was the methodology successful?

There were difficulties persuading sub-contractors that they really did have to allow for building movements, drain water away, provide continuity of vapour barriers, etc., but many compensations also. Particularly satisfying was the gradual realisation by the client, architect and management contractor alike that the Arup fabric engineering team were the only ones who could resolve the complicated technical issues posed by a cladding project of this size and complexity.



6. Original architectural conception for mullion detail.



7. Modified mullion detail.

The future

The lessons learned on the Lee House are being evaluated and recorded for future projects. In particular, we are currently reviewing and modifying specifications before our Lee House experience is lost under pressure from the next job. This will help future generations of fabric engineers in Arups.

As a result of our experience on Lee House we are obtaining other fabric engineering commissions ranging from conceptual engineering advice to architects through complete design drawings and specifications for cladding projects to technical audits on building fabric and building pathology. A series of fabric initiatives are in place to develop standard forms of fabric engineering conditions of engagement, brochures, and explore new markets and new technologies.

We are playing significant roles in the work being carried out under the guidance of the Centre for Window and Cladding Technology at Bath, we are assisting the BSI working group involved with the production of Eurocodes for cladding and we are involved with Institution of Structural Engineers on the preparation of a cladding design guide for structural engineers.

The concept of fabric engineering, as another skill in our industry remains controversial. Whatever it is finally called and whoever does it, it will need doing even more in the future.

8. Window — window mullion: detail.
(Photo: Roger Ridsdill Smith)

Credits
Client:
MEPC plc
Architect:
Terry Farrell & Co.
Management contractor:
Mowlem Management Ltd.
Quantity surveyor:
Cyril Sweett & Partners
Illustrations:
Martin Hall

The National Gallery Sainsbury Wing

Architects: Venturi and Scott Brown

David Brunt
Alan Pepper

Introduction

This article is intended to illustrate and put into context key issues in the engineering design of the building. They are biased towards its environmental systems because of their importance for the display of the early Renaissance paintings, which include some of the oldest in the National Gallery's collection, dating from 1260 to 1510 AD.

The design submitted by Robert Venturi and Denise Scott-Brown in January 1986 as part of the selection process included a study of renowned art galleries and the way in which the lighting of them served the best interests of the viewing public as well as preservation of the art works. Dulwich Art Gallery, designed by Sir John Soane, influenced their competition design and illustrated the benefits of a predominantly top-lit configuration, allowing maximum use of wall space for display and good control of lighting through mixing natural and artificial light from above.

The detailed brief listed the works to be displayed, and this enabled the architects to create gallery shapes which met the client's wishes for the arrangement of the paintings. This factor, together with the irregularly-shaped site, led to a totally asymmetric and non-modular plan at gallery level. This theme was extended to the other floors, two at ground level and above, and two below ground, and has resulted in the creation of some generous and exciting public areas in which the architects have in places expressed their deep interest in 'contradiction and juxtaposition'.


1.


2.

Main design criteria

- To display some 240 paintings in a variety of media, including canvas, wood, fresco, tempera, and oil (out of the National Gallery's collection of over 2000)
- To maintain closely-controlled environmental conditions in the Gallery and picture storage and packing areas, as listed below:

Summer temperature 23°C with ± 1°C variation
Winter temperature 19°C with ± 1°C variation
Seasonal temperature change of 0.25°C per week
Relative humidity 55% with a ± 5% variation

- Special filtration to limit gaseous pollutants such as sulphur dioxide, carbon monoxide and oxides of nitrogen, which can produce damaging acid solutions when combined with the interstitial condensation that can occur within the paintings
- To create a high mass building with an external thermal insulation value not exceeding 0.25W/m^{2}°C
- To utilize controlled natural daylight to limit the amount of harmful ultra-violet radiation to no more than 650 kilolux hours per year. This permits average luminescence of approximately 200 lux during viewing time
- Low pressure hot water supplied from parent building at a temperature of 82°C
- Chilled water from parent building at 7.2°C.

The contracts

Late in 1986 the design teams and client advisors decided that the construction management route was appropriate, and following submissions by a number of leading contractors Sir Robert McAlpine were appointed early in 1987.

It was originally intended that the total number of trade packages should be kept to around 20, with the structure and M&E services provided through 8. However, the large number of different architectural finishes led to a significant increase in the number of trade packages, with a final total close to 50.

A year's design work was carried out before the appointment of the construction manager, during which time Ove Arup & Partners attended to preliminary programming and site investigation work, including an archaeological dig by the Museum of London.

3. **The accommodation** Total floor area: 10 800m^2

Colour key to all levels illustrated ▶ 🟨 Gallery space 🟫 Other public areas

Level 1
(Main basement, 2000m^2 net)

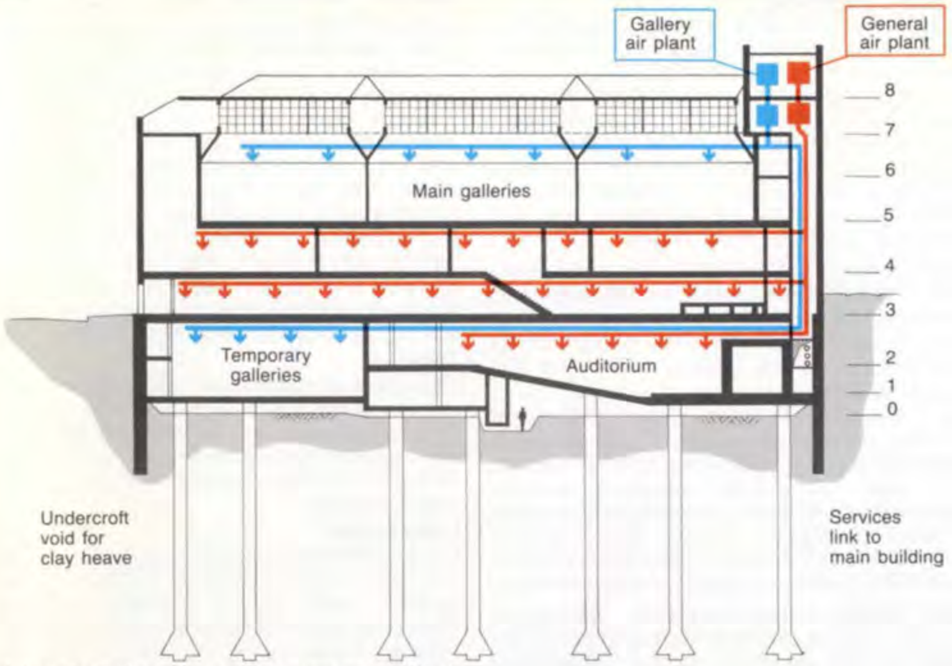
Galleries for temporary exhibitions
A 350-seat auditorium with stage
A secure picture store with picture packing area
A small video cinema (30 seats + standing room)
Storage rooms and warders' rooms
Toilets

Level 2
(Basement mezzanine, 500m^2 net)

Auditorium control and translation room
Tunnel link to the main building
Public toilets

Level 3
(Ground level, 1850m^2 net)

Entrance foyer
Cloak storage
Shop
Store
Twin vehicle loading bays
Electrical plantrooms



4. Longitudinal cross-section showing air-conditioning.

5. Basement undercroft.

6. Typical plantrooms.

Foundations

It was necessary to ensure that ground movements would not cause damage to adjacent buildings, and a movement monitoring system was established to record the rate and extent of movements over an area that included points up to 60m from the site boundary. Actual horizontal movements proved to be approximately half the value of those predicted by a finite element mesh analysis, the largest being in the order of 15mm.

The building weight of approximately 25 000 tonnes is supported mainly on under-reamed bored piles, but with a small proportion carried by the perimeter secant pile wall. To minimize horizontal ground movements, the ground level slab was cast after piling and acted as a lateral prop to the perimeter pile wall as the basement excavation was carried out in a 'top down' approach.

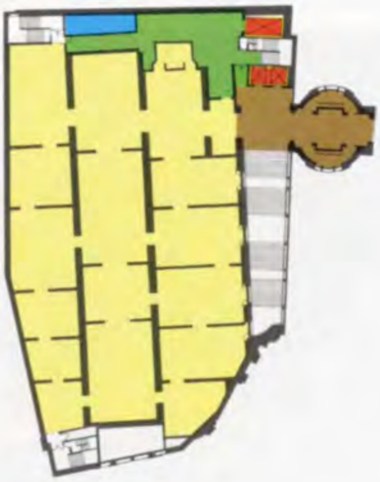
Inclinometers were built into eight of the secant piles to enable movements to be measured. The sequence of excavation to full depth was carefully co-ordinated with the area-by-area casting of the basement floors that act as horizontal props to the perimeter wall. This also minimized lateral movements at the lower levels where earth pressures are very large.

The 20 000m^2 of material that had to be removed to form the basement was excavated through apertures in the ground floor slab within a five-month period as programmed. Beneath the lowest basement a drained undercroft space (with minimum headroom of 750mm) was formed to allow the anticipated 100mm of clay heave and to prevent any build-up of water pressure under the basement slab. This undercroft also allowed the drains to be laid after most of the structure was complete, as well as providing easy access to them for maintenance.

🟩 Non public areas 🟦 Services plantroom 🟥 Lifts ☐ Void

Level 4
(Mezzanine, 1700m^2 net)

Micro Gallery
Restaurant/kitchen/coffee bar
Trustees' conference rooms
Warders rooms
Public toilets



Level 5
(Main gallery, 1900m^2 net)

16 gallery rooms
Link to the main building
Store

Levels 6, 7, 8 (not illustrated)
(Plant rooms, totalling 1100m^2 net)

Superstructure

The irregular pattern of columns, and the restricted headroom caused by the need to fit two storeys into the 8m height difference between entrance pavement level and the link to the upper gallery of the existing National Gallery building, led to the adoption of reinforced concrete flat slab floors on reinforced concrete columns.

The two loading bays, unavoidably situated over the Level 1 auditorium, are of discontinuous double floor construction with non-rigid bearings to reduce the transmission of noise and vibration.

The structural steel roof structure is geometrically complicated because of the gallery plan layout, varying gallery heights, and the need to provide routes for natural lighting and the all important air-conditioning ductwork.

Air-conditioning

The need to provide high quality air and closely controlled temperature and humidity conditions in the spaces containing the works of art led to the building being divided up into two basic zones, to cover critical and non-critical spaces. The air-handling system for the critical spaces includes activated carbon filtration and stringent humidity control whereas other areas did not require such thorough treatment. The carbon filters are located in the air-handling units where they are able to filter recirculated as well as fresh air. The air-conditioning system is controlled by a building management system (BMS).

The critical system consists of two variable air volume air-handling units connected in parallel. From the air-handling units the air is fed through ductwork to the sub-zone areas where humidification is adjusted individually. Each sub-zone serves up to six adjoining galleries.

The humidity in each sub-zone is adjusted by a pair of thyristor-controlled electric steam humidifiers. The air is supplied at a constant humidity of 80% and at a controlled temperature varying seasonally between 12°C and 15°C. We developed bespoke software algorithms to ensure that free cooling remained within economic limits.

In every gallery there are three wall-mounted sets of sensors that measure temperature and humidity. The closest values from two of the sensors are automatically selected and the third one rejected. This redundancy approach was a requirement of the brief and provides some protection against sensors going out of calibration.

The BMS is used to provide close control,

maximum energy efficiency, and monitoring of plant performance. It is also the basis of efficient maintenance procedures. Standard and specially written software has been used to provide a comprehensive control and monitoring system.

Load simulation tests were carried out after completion to represent the design occupancy of a person for every 4m^2 of floor space. Arrays of 100W bulbs, each representing one person, were used to simulate sensible heat. Latent heat was simulated by electric kettles wired through variax transformers to give an evaporation rate equal to 60W per person. An appropriate correction for the sensible heat loss of each kettle was made by adding 100W to the kettle supply and taking out one of the 100W bulbs.

The control signals to the BMS were monitored during the testing and only minor re-tuning of controls to reduce VAV box cycling was necessary to achieve design conditions.

Smoke testing was carried out both during and independent of the occupancy load simulation to demonstrate that air velocities could be kept low and reasonably uniform within the occupied space and its surrounding walls.

Gallery lighting

The benefits of some degree of day-lighting, which include outside awareness and changeability, outweigh the harm from its transmission of ultra-violet radiation, particularly when the latter can be strictly controlled. As the UV radiation does not contribute to the visual process, it is normally controlled in all modern museums and galleries to a level of 75μW per lumen. In the Sainsbury Wing the acceptable level is a more stringent 10μW per lumen.

Above the clerestory windows to the galleries and beneath the main roof-line are illuminated walkway routes that accommodate a network of blinds automatically operated to control the amount of natural lighting passing to the galleries below.

A 1:5 scale model and a full-scale mock-up of gallery space were used early in the project to test the design assumptions and to confirm the final brief. As a result, artificial lighting was incorporated at high level to complement and supplement daylight for viewing, and as a main source during the hours of darkness. It also provides illumination for security and maintenance.

The lighting angles have been designed to avoid reflective glare from the paintings and the picture lights are track-mounted 12V tungsten halogen fittings in a recessed slot around the perimeter of the lantern ceiling and across the centre of the larger galleries.

Fire precautions

A detailed fire strategy evolved from discussions between Westminster City Council, the architect and ourselves. Protection of the paintings includes prevention of water damage from internal sources and rainwater drainage. A sprinkler installation was not included in the original brief but we convinced the client that sprinklers should be included in certain non-gallery areas. A single sprinkler coped with the firebomb that went off in the shop during the early hours of Sunday 15 December 1991.

The high security requirements of the building necessitate that smoke extraction be by mechanical means. The air-conditioning systems' return air ductwork, suitably fireproofed, is used to draw smoke from the area of the building affected by fire. Smoke extract fans rated to withstand 615°C for a period of 90 minutes are linked to return air ductwork via dampers isolating the normal return air fans.

Acoustics

Enjoyment of the pictures, with adequate intelligibility for effective guidance, were the prime acoustical requirements in the gallery areas. A survey of reverberation times in a selection of galleries in the main building as well as in the Tate Gallery revealed four different characteristic shapes to the reverberation time against frequency curves. The brief laid down that 'large areas of highly efficient acoustic absorbent material should be avoided' and the end result was the incorporation of *Mikropor* perforated panels into the ceilings and inclined areas between walls and clerestory glazing. Acoustical advice for all aspects of the design of the building was provided from the concept stage onwards and was of considerable influence on the design of the auditorium as well as the isolation of high noise levels in local streets.

Lifts

There are two passenger lifts for public use and two additional special-purpose hydraulic lifts. One is a picture lift with large-volume car capacity, rated at 5 tonnes, whilst the other is a small kitchen lift serving the ground floor and mezzanine levels only.

Conclusion

Construction commenced in mid-January 1988, and HRH The Prince of Wales, who is a National Gallery Trustee, laid the foundation stone in March that year. The building was occupied by National Gallery staff in late autumn 1990, so that they could embark on the fitting-out and picture hanging work. After building handover, the simulated load tests were carried out on the air-conditioning. These tests provided additional confirmation to those responsible for the collection that the environment in the Sainsbury Wing was stable and fully controlled before any exhibits were transferred from the main building. The building was finally opened by the Queen on 9 July 1991.

Computer technology has been incorporated by National Gallery staff for the benefit of the viewing public in the information room on Level 4. This contains a 'Micro Gallery', thought to be the most advanced fully-digital interactive media system of its kind in the world, being able to display over 2000 paintings with many secondary illustrations, texts and animated sequences. These are reproduced on Radius 19in colour monitors providing a screen resolution of 82 dots per inch. The installation comprises 12 Apple Macintosh IIfx computers each with 8MB of RAM and a dedicated 1·3 gigabyte hard disk drive. The system runs sufficiently fast to permit the viewer to browse through it using the touch screen with an access time of no more than one second from screen to screen. Another example of Art and Science blending happily together!

7. Level 5: view through link to existing National Gallery.

8. Smoke extract fans.

9. Level 1 auditorium.

Credits
Client:
N.G. Services Ltd.
(a company formed by the Donors solely for the provision of the building)
Architects:
Design: Venturi Scott-Brown Associates
UK liaison: Sheppard Robson
Structural engineer:
Ove Arup & Partners
M&E services engineers:
Ove Arup & Partners
Jaros Baum & Bolles (New York)
Quantity surveyors:
Gardiner & Theobald
Mott Green & Wall (Building Services)
Lighting design:
Fischer Marantz
Acoustics:
Arup Acoustics
Construction manager:
Sir Robert McAlpine
Construction Management Ltd.
M&E services installation contractor:
Crown House Engineering Ltd.
Photos:
1: Ernie Hills; 2: David Brunt;
5-8, 10-11: Peter Mackinven;
9: © National Gallery Publications Ltd.
Illustrations:
Fred English

10. Clerestory glazing showing natural lighting control mechanism.

11. Typical gallery.

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