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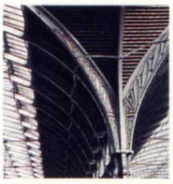
Front cover: West Yorkshire Playhouse
(Photo: Alastair Hunter Photography)

Back cover: Body presses for Jaguar at GKN, Telford:
the 'Jardine project' (Photo: Peter Mackinven)

The Iron Revolution
Patrick Morreau



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The century from 1780 to 1880 saw the use of iron as a central factor in structural innovation, with far-reaching consequences for the roles of architects and engineers in the building process.

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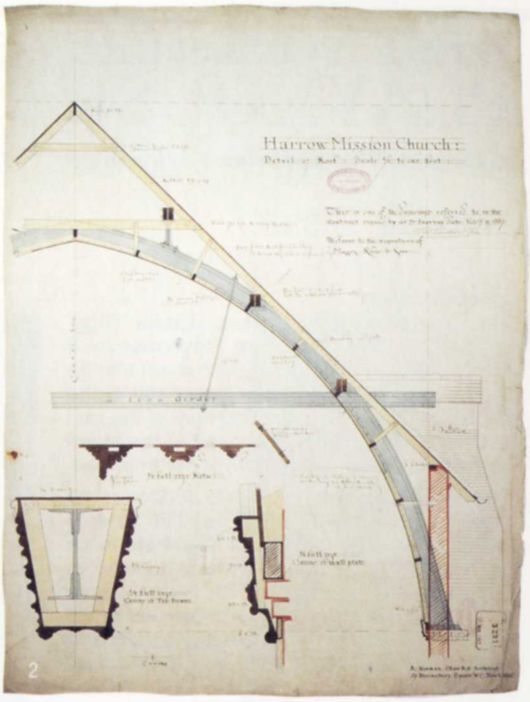
The Iron Revolution

Patrick Morreau



During June and July 1990, the Royal Institute of British Architects mounted an exhibition 'The Iron Revolution: Architects, Engineers and Structural Innovation, 1780-1880'. Ove Arup & Partners were a sponsor of this exhibition, which reflected well some of our abiding concerns: collaboration between all involved in making buildings; innovation in materials and construction techniques; advances in engineering analysis and design; and the appropriate expression of the engineer's contribution.

The exhibition itself was an example of collaboration and support from developers, builders, architects and engineers. Apart from Arups, the sponsors were the RIBA, the Institution of Civil Engineers, the Institution of Structural Engineers, YRM, W S Atkins, Harry Neal Ltd, and Land Securities, the principal contributor to the cost.

The intention was to explore how the adoption of iron as a building material altered the roles of architects and engineers in the building process. Every history of architecture cites famous examples of buildings which relied upon iron for function and effect — the Coal Exchange, the Reform Club and many pioneering commercial buildings — but few explore how the designs for them evolved and exactly who contributed the necessary structural knowledge. This exhibition revealed how the design process changed during the 100 years when iron was the principal means of technical innovation. Directly, or indirectly, the drawings shown raised issues pertinent to all involved in making buildings today, more than a century after the close of the period covered.

One issue is leadership in design. The drawings may look harmless, but the history they tell is punctuated by uncertainties and conflicts over the division of authority in design and construction: once buildings had reached the kind of scale and complexity that required a specialist structural contribution, the roles of the different building professions fell into new alignments: the results of those changes are still being felt today.

As the professions took shape, the new building types that were to absorb many of their members' energies were coming into being — railway stations, exhibition halls, conservatories and the many institutional and civic buildings of an urbanizing world. These demanded floors and roofs of unprecedented spans; and for that reason, as much as because of their novelty, they were often the subject of dispute over who should take the lead in their design.

Such controversies find echoes in today's arguments about project leadership, project management, design-build, and the roles of the architect and engineer. The interesting difference is that, in the 19th century, the issues arose from new techniques of *making* buildings; today they arise from new ways of *organizing* the making of buildings.

Another issue raised by the drawings that were exhibited was that of the expression — or suppression — of the iron structure in the completed building. Then and since, as now, different and extreme positions were adopted. But whatever the style presented, the buildings shown reflected the confidence, the prosperity, and the exuberance of their era. In the 20th century, buildings in steel — the successor material — have been the built expression of the machine age. The past two decades have given us buildings, the direct descendants of those in this exhibition, which are splendid examples of structural expression: Centre Pompidou, the Royal Exchange Theatre in Manchester, the Hongkong Bank, the David Mellor factory at Hathersage, to name but a few. In each of these, and in many others, the relationships between architect and engineer which enabled the Iron Revolution to take place has been reaffirmed.

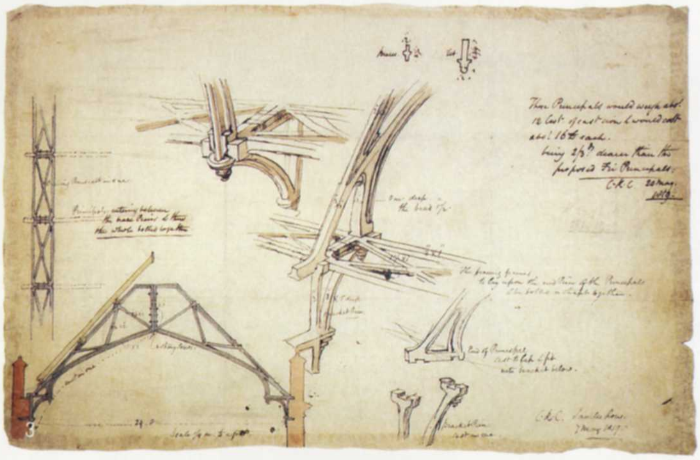
1. 59-61 Mark Lane, London (George Aitchison Jnr., 1864). Speculative office block with iron frame behind a Ruskinian Gothic facade.

2. Harrow Mission Church. Detail of roof.

3. Drawing of an iron roof by C.R. Cockerell, 1819.

4. Main staircase, Midland Grand Hotel, St. Pancras (G.G. Scott, 1867-73).

Illustrations courtesy of Robert Thorne and RIBA.



WEST YORKSHIRE PLAYHOUSE

Architect: The Appleton Partnership

Alastair Bisset

Introduction

The Yorkshire-born actress, Diana Rigg, opened the West Yorkshire Playhouse on 8 March 1990. It occupies a prominent site on the famous (or notorious) Quarry Hill in the centre of Leeds. The development of the rest of Quarry Hill, initially proposed at the same time as the theatre, has not yet materialized.

The Playhouse comprises two auditoria: the larger, the Quarry Theatre, has 750 steeply raked seats, and features a thrust stage on the level of the front row, the aim being to create an intimate space with the audience embracing the stage. The smaller Courtyard Theatre is entirely flexible in its seating and performance arrangements, and can accommodate up to 350 people. Other areas include a spacious and dramatic foyer restaurant and bar which is designed to attract the casual theatregoer and move away from the idea that 'going to the theatre' is only for special occasions. The highly professional workshops for the production of scenery and props have facilities which would be the envy of many a commercial manufacturing enterprise.

Apart from designing a successful theatre complex, the architects also set out to produce a substantial civic building in the Leeds tradition, to which end exposed patterned brickwork has been used extensively both outside and inside the building. Natural lighting has been used as far as possible, not only for public spaces, but also workshops, wardrobe, dressing rooms and other backstage facilities. In consequence, many of these areas have interesting views out over the city.

The site

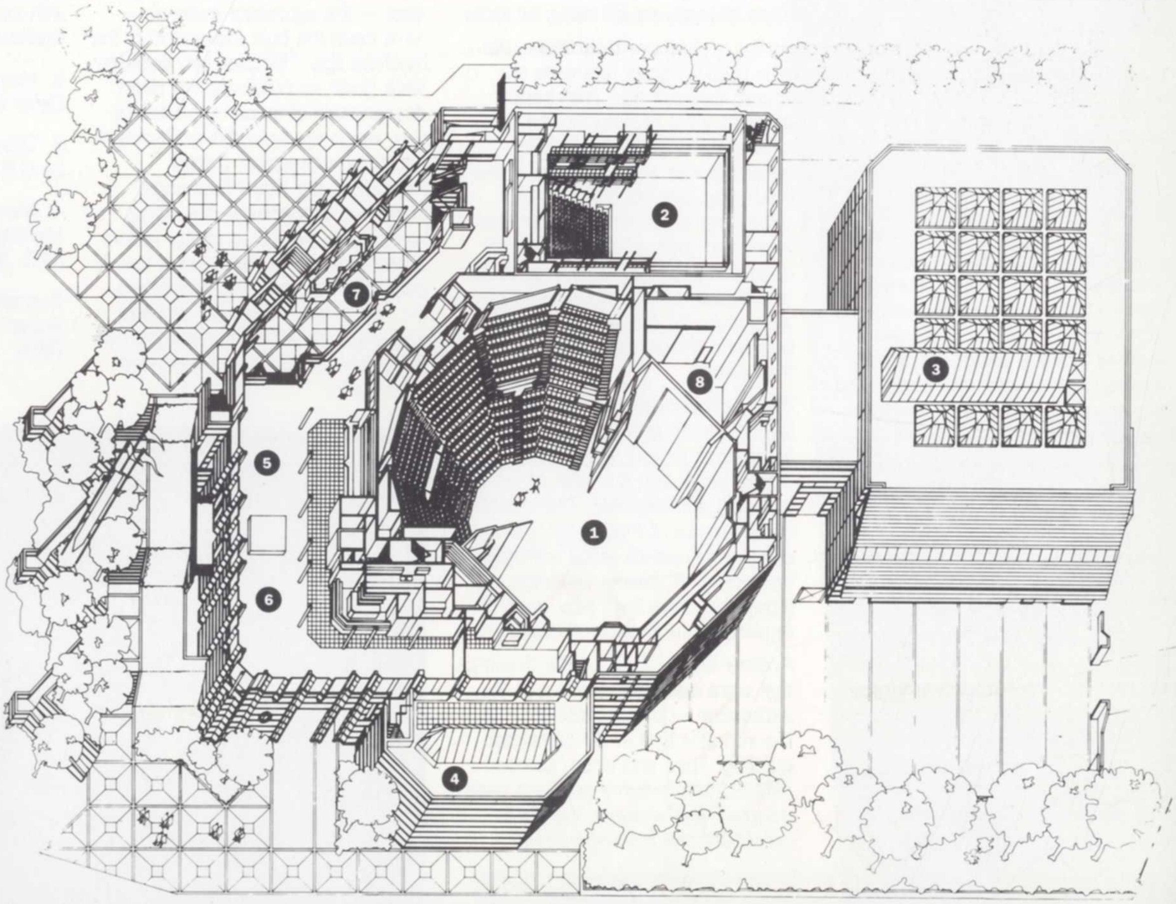
Quarry Hill was previously occupied by tenements, demolished in 1933, and subsequently by multi-storey flats which were in turn demolished in 1968. These latter flats were revolutionary in their time, constructed as they were with steel frames and precast panels. They attracted much international attention but, like many of their successors, they eventually fell into disrepair and degenerated into slums. Demolition materials from them had been used to land-form the site prior to seeding and planting. Much building rubble, including two complete air raid shelters, was removed prior to formation of the strip foundations on the underlying rock. The lowest floors are carried either directly on these foundations or by brick sleeper walls. Local deep excavations into the rock were required for both the lift pits and extensive under-stage areas.

Auditoria

From a structural engineering point of view, the Quarry Theatre was the more interesting and challenging of the two auditoria. Because of the plan shape and differing levels, the geometry of the interface of the building with the ground was most complex. The reinforced concrete ground slab had to be shaped exactly to meet the needs of seating, stage and flytower, with all the associated pits and provision for flexible service support which are a feature of a modern theatre. The roof structure supports not only the weatherproof membrane, but also a plethora of air-conditioning and electrical services and equipment. The roof trusses also carry the galleries which provide support and full standing height access to the stage lighting. Particular engineering problems were generated by the thrust stage form of the auditorium with its requirement for all-round actor access and wide angle of audience sight-lines. This resulted in a 25m

1. Projection of the West Yorkshire Playhouse incorporating the Quarry Theatre and The Courtyard Theatre.

Key:
1. Quarry Theatre
2. Courtyard Theatre
3. Workshops block
4. Rehearsal room
5. Bar lounge
6. Restaurant
7. Foyers
8. Scene dock

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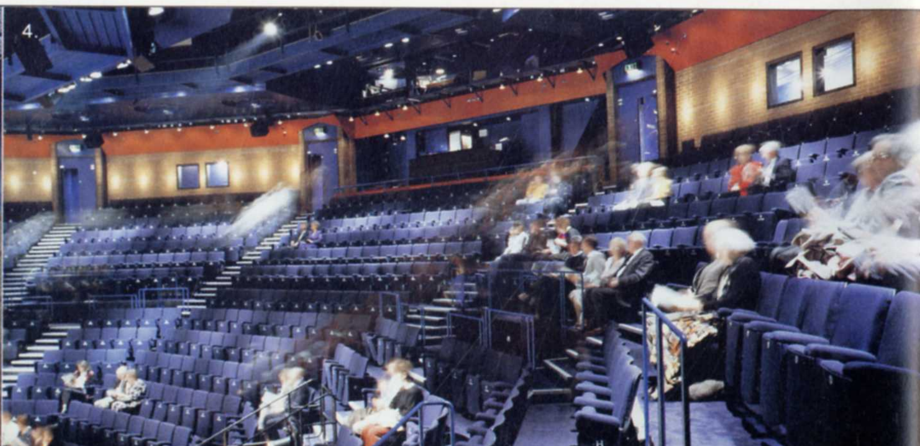

4.

5.

wide stage opening across the front of the 24m high flytower. Apart from supporting external glazing and cladding, the flytower supports the fly grid, two levels of access galleries, more stage lighting and counterweight loading galleries. The flytower is open at the back to accommodate the wagon (the flat platform on rails used for moving scenery rapidly on and off stage) and stage-ready scenery. It is also open to the side so that up to 7m high pieces of prefabricated sets may be brought directly from workshop to stage.

The Courtyard is a 25m × 18m × 10m high theatre-in-the-round. Although more structurally straightforward than the Quarry, it does feature a suspended grid over the stage area, lighting gantries and viewing galleries. The suspended floors of in situ reinforced concrete surrounding the main auditorium accommodate kitchen, restaurant, boardroom, greenroom, dressing rooms, wardrobes, control rooms and so on. The complex geometry of the roof shape with its prominent flytower echoes the complexity of the function of the building enclosed below. The major spans over the two auditoria, the restaurant and over the workshop are all in steelwork. Timber box beams supporting the roof give a warm, domestic feel to the dressing rooms.

Heating and ventilation

The air-conditioning system has been designed to deal with the demanding design criteria for the environmental conditions. The air-conditioning system meets the exacting 20/25 Noise Rating requirements laid down by the acousticians. The Quarry is fully air-conditioned and the exposed high level gantries and complicated roof shapes presented a challenge to achieving good air movement from the high level diffusers served by exposed ductwork. Air is exhausted from high and low level in such a way that temperatures within the theatre at occupant head height are controlled within a narrow band. Outside the main auditorium the remainder of the building is heated and ventilated with economy in mind but is designed to meet the basic but different special needs of each space.

Electrical services

The West Yorkshire Playhouse shares a level of sophistication in electrical engineering with the best-equipped buildings of its type. Each auditorium has separate arrangements for the control of power and lighting. The stage production lighting is computer-controlled. A high technology sound system is fitted throughout and includes special facilities for the hard of hearing. The communication systems ensure efficient running of the complex in terms of stage management and customer satisfaction and include public address, stage sound relay, stage manager instructions, art lights, video relay and paging. The production lighting rig supports 300kW of stage lighting. House, backstage, blue and emergency lighting are all separately controlled and each is interlinked with the others to give a highly controlled system. Extensive external lighting is used to illuminate the building during the winter months and attract patrons to its doors.

Credits

Client:
West Yorkshire Playhouse

Architect:
The Appleton Partnership

Structural and services engineers:
Ove Arup & Partners Scotland

Quantity surveyor:
Davis Langdon & Everest

Photos:
2: Ove Arup & Partners
3-6: Alastair Hunter Photography.

Drawing:
The Appleton Partnership

6.

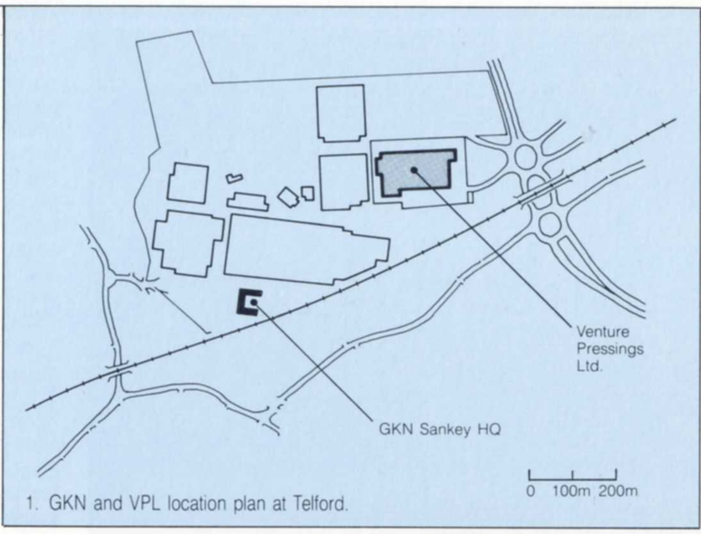
JARDINE PROJECT

John Harvey
Bryan Clifford

Introduction

'Jardine' is the codename for a project to build a press shop for Venture Pressings Ltd. In the early days the scheme required a degree of confidentiality, and the name was chosen simply because Douglas Jardine was the captain of the MCC team during the 1932-33 Australian tour known as the 'body line' series: the association between bodyline and quality car pressings seemed appropriate.

Venture Pressings is a company jointly owned by Jaguar and GKN. The joint venture came about because Jaguar needed a dedicated and high quality means of production, whilst GKN had suitable press machinery and a factory building suitable for conversion. This was on the perimeter of the large GKN Sankey industrial complex in Telford, Shropshire, and could be readily fenced off from the remainder and made into a separate operating unit. It had been built in the 1950s, and at the time we started this project was producing tractor cabs.



1. GKN and VPL location plan at Telford.

The presses came from elsewhere on the site, and from a press shop in Bilston, which was later to close. There were 54 in all, weighing up to 350 tonnes each.

Arups were appointed on terms similar to the normal ACE Conditions of Engagement to design and manage the construction works for the conversion of the existing building to accept the new pressing operation, and to expedite the removal, refurbishment, and installation of the presses. We were also responsible for specifying and procuring scrap removal conveyors, which ran below the press lines.

The building works included:

- Trench foundations up to 6m deep, 8m wide, and 60m long for each of the nine press lines
- Stripping out of all redundant services
- Demolition and rebuilding of part of the factory
- Provision of new services throughout, including compressed air and power systems
- Refurbishment of the building envelope and office areas
- Renewal of floors
- Addition of new overhead cranes and strengthening of the existing structure to receive them
- External works and ring main services.

Our management duties included:

- Planning and programming — through both design and construction stages to achieve completion at the date required
- Cost estimating and control — generating an initial agreed cost plan and managing works at all stages to achieve this
- Contractor appointment — by competitive tender, selecting a series of package contractors, each responsible for a portion of the works
- Construction management — maintaining continuous control of all package contractors concurrently working on the site, to achieve compatible working practices, quality standards and cost and time objectives.

To fulfil our responsibilities we needed to supplement our own resources in the fields of production engineering and architecture, and thus engaged Rossmore Warwick and the Harper Fairley Partnership respectively with whom we worked throughout as an integrated team.

Scheme stage

At the time of our appointment, the client had decided on his production layout. Our initial, five-week, task was to develop all building design work to scheme stage in accordance with this layout, and then a broad elemental cost plan leading to an overall budget proposal. It was also necessary to plan the construction works and the organizational approach in some detail.

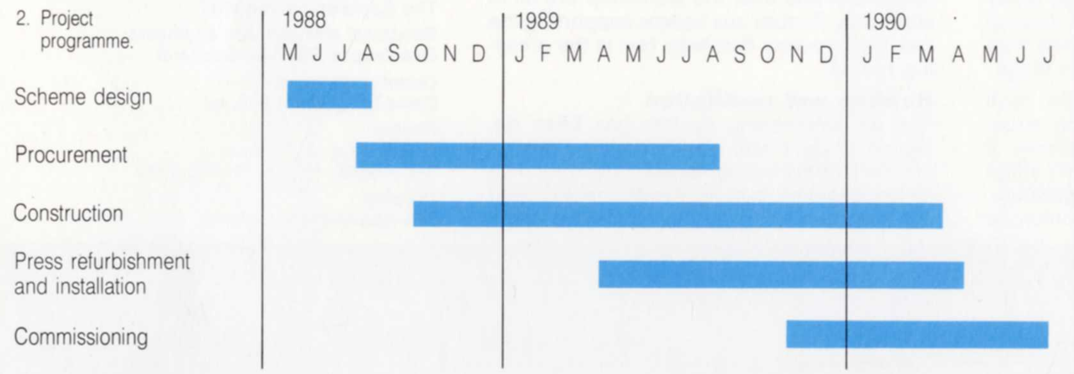
During this period we were working closely with the client team, and with our advice it became evident that some adjustments to the building geometry could bring significant improvement to the production layout. A review of the project was therefore called. The operating logic of the press shop was re-examined from basic principles, existing building geometry constraints were questioned and alternatives researched. Detailed analyses of plant and component movements were undertaken, and construction and plant installation implications assessed. In all, eight alternative layouts were derived and analyzed from all points of view. A final scheme was selected, and the engineering design work and cost planning reworked into a revised scheme stage report which set the guidelines for the remainder of the project.

The final scheme necessitated the demolition and rebuilding of part of the factory, but the resultant improvements in the production layout, together with elimination of some non-essential elements, gave much better overall value.

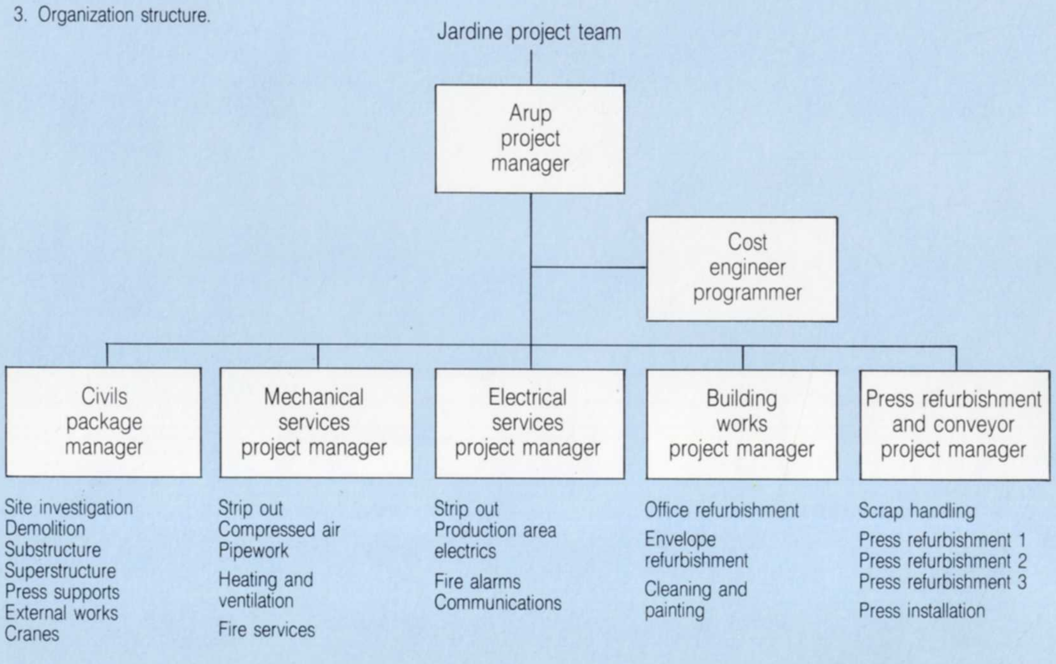
Procurement stage

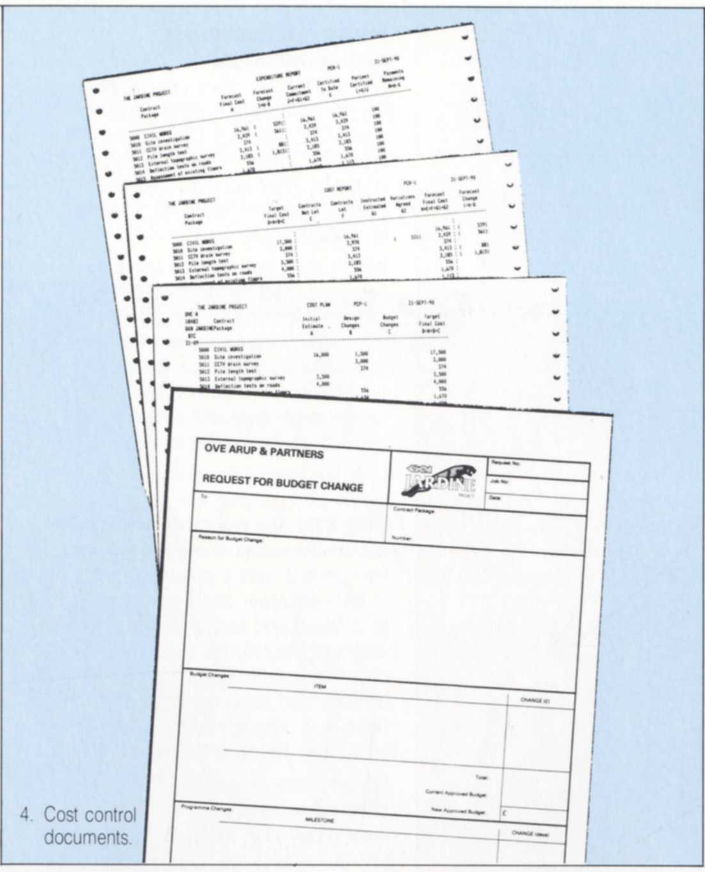
Although the review lasted 14 weeks, the completion date remained unaltered. The construction management approach made this achievable,

2. Project programme.



3. Organization structure.





OVE ARUP & PARTNERS

REQUEST FOR BUDGET CHANGE

Request No:

Job No:

Date:

To:

Contract Package

Number:

Reason for Budget Change:

Budget Changes

ITEM	CHANGE (£)
Total:	
Current Approved Budget:	
New Approved Budget:	£

Programme Changes

MILESTONE	CHANGE (days)

4. Cost control documents.

as the 'seamless' transition (indeed, integration) of design and construction phases eliminated the time-consuming handover of responsibility. The design could be developed in a way which fully acknowledged the construction time implications, as we retained authority over both activities.

Four weeks after the client accepted our final scheme proposals, the first contractors began stripping out the existing services, as well as making the necessary service diversions to keep a paint shop operational in part of the building.

The building work and the press refurbishment divided naturally into about 35 work packages, and we arranged these by discipline under the responsibility of five package managers who led teams to design and specify the works and prepare tender documentation. They prequalified contractors, recommended tender lists to the client, invited tenders and received them, and made recommendations on appointments.

For work where it is common practice for contractors to undertake elements of detailed design, this responsibility was included in the contracts. These were included in the foundation package as well as those for structural steel and services.

All contracts were directly with the client, and we acted as engineer, supervising officer, or agent, according to the type of contract used. Wherever possible, these were standard forms and were chosen to suit the particular trade package. The foundations were let on the ICE form of contract and the compressors on the IMechE/IEE form. Where there was an element of contractor design (the steelwork and the services installations) the JCT design and build form was used, but straightforward construction to our design was let on the JCT form without quantities. With the exception of the form of contract offered by the National Federation of Demolition Contractors, which appeared biased towards the contractor, we were able to use the standard forms with few modifications.

As far as the Venture Pressings board was concerned, keeping within budget was as important as completing on time. A ceiling cost of £38M was approved and could not be exceeded. If at any time the cost forecasts indicated that this was likely, the scope of work had to be reduced to bring the forecast back on target. To control the cost of the portion of the works for which we were responsible, we used an elemental cost model which could be easily and regularly updated to take account of change so that the forecast final cost was always readily available.

The key to cost control lay in handling changes, and here we had the full co-operation of the client's Managing Director. Each time a change was requested by a member of the client's team, a simple form was completed by the package manager, setting out its cost and time effect. This had to be signed by the Managing Director before funds or time could be made available from the Contingencies. Very few were signed, in fact, because as soon as the effect was made clear, the alteration was stopped unless it was absolutely necessary.

Cost control at the tender appraisal stage was crucial. If tenders were returned above the target value, they were quickly examined and the content reduced to get the package within budget or at least to the bare necessities. Packages for the essential works, such as press line foundations and production line services, tended to be let earlier than those for the less essential works such as decoration and office refurbishment. This allowed us to make adjustments to the contents of the later packages to suit the funds available.

Construction stage

Good co-ordination of all these contract packages was essential. A master programme set the start and phased completions for each package, and each contractor provided a detailed programme to suit his control dates. Minor adjustments to the master programme were sometimes necessary to suit the contractor's preferred method of working. The master programme was modelled on the Hornet critical path network system and updated regularly to take account of changes and reflect progress. Secondary co-ordination was achieved through day-to-day direction of activities by our package managers and weekly co-ordination meetings. These would take place on Fridays and managers of all the contractors working on site would attend. After dealing with general matters, each in turn would simply tell the others what he intended to do during the coming week. Problems like contractors wishing to work in the same area were always solved amicably; in fact, contractors welcomed the opportunity to assist in the smooth organization of the work and the meetings helped to build team spirit.

As soon as sufficient package contracts had been let, we transferred the centre of control to site; the project manager was established there and the package managers joined him as work in their disciplines built up. Three were able to follow through the whole process of design and site management; the others handed over their responsibilities to site-based staff as the contract packages were let.

Contractors' detail design submissions were reviewed on site, and co-ordination meetings also held there. Co-ordination was done a bay or section of the factory at a time, and the contractor with a dominant service in the area would present his preferred arrangement and routing so that the others would comment and arrange their services to suit. This very direct relationship between designers and contractors speeded the detail design, and gave the contractors a role in developing optimum solutions to which they were committed.

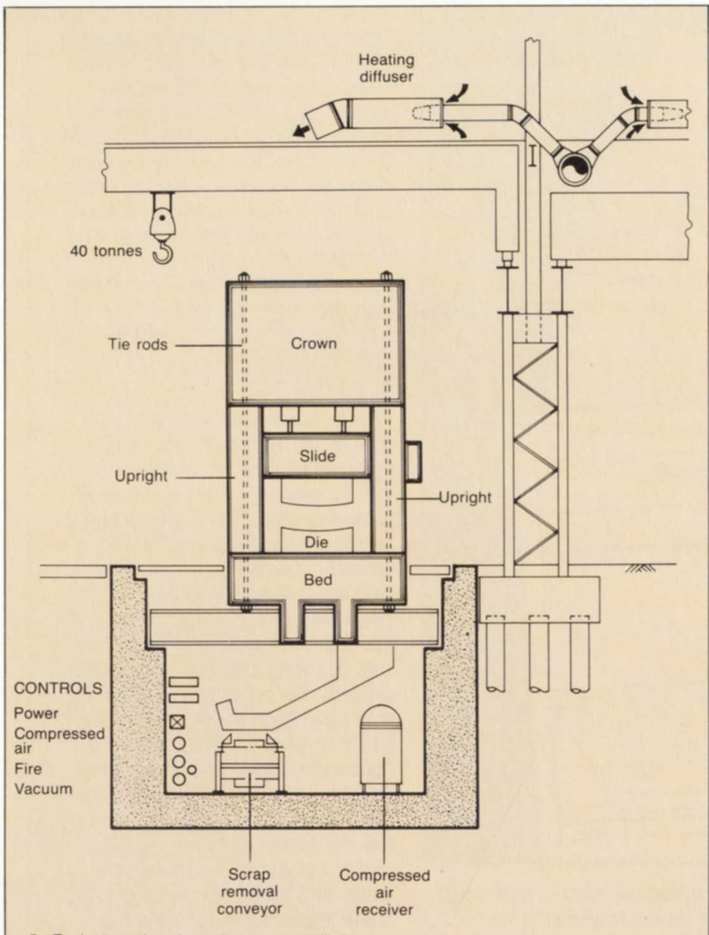
Package managers also held separate progress meetings with their contractors where quality and payment issues were discussed. Progress was then summarized and presented to the client bi-weekly. We tried to organize these meetings so that they were forward-looking and problem-solving. We tried to avoid dwelling on past events and blame allocation.

Traditional bills of quantities were not used. At the time of tender for each package we considered that our client's requirements were firm and were sufficiently well-defined to justify tenders based on specifications and drawings. Tenderers were required to price for complete sections of work but if these were large, they would be sub-divided to ensure that the contractor would achieve a reasonable cash flow. Contractors were also required to price a schedule of rates to facilitate valuation of variations.

Payments were not certified until a pre-defined section of work was complete and to the satisfaction of the package manager. For services work, this meant that sections had to be installed and the initial testing carried out before payment. The package manager therefore had the bargaining power of the full value of the section of work to ensure that it was operating correctly and finished properly. For some contracts there may have been a small cost penalty for this method of payment, in that contractors could have had greater financing costs than for a traditional system. On balance, we considered that the added incentive to finish sections ahead of the valuation dates, and to the standards required, made this worthwhile. In any case, there would be a corresponding reduction in financing costs for our client. As with many projects, the client did change his requirements during the course of the works rather more than we had anticipated. For some packages, the schedule of rates proved to be inadequate to deal with all the variations, and there have been some protracted negotiations over what can be considered a fair valuation.

Quality management systems were specified but we got a varied response according to a contractor's previous experience in using them. We did not insist that they should be *BS5750*-registered because, at that time, this would have excluded most of the construction industry. Instead, we specified the basic elements of a QM system similar to *BS5750*. Suppliers of mechanical plant such as compressors and cranes had been using these systems for some years and had no difficulty in complying with the requirements. The quality of their work was generally good, as was that of one of the structural steelwork fabricators who had an established system.

We got a mixed performance from the remainder and our level of supervision had to vary to suit. Two small local builders won the packages for envelope and office refurbishment. They were not at all familiar with QM systems and in these cases we used the traditional supervisory roles of architect and clerk of works. One of the civil engineering contractors was working towards the use of *BS5750* systems for the first time. We helped him prepare a project manual for the job, and this was used with some success. ▶



5. Typical section through press installation.

6. Right: Building before refurbishment.

7. Below: After refurbishment.

Press refurbishment and installation

There were four principal contracts for refurbishment, one for the strip down, moving and rebuilding of the presses. The client team decided the scope of work and checked its quality, whilst we were responsible for expediting it.

Initially the client wanted to let a single contract for all this work with the requirement that the presses be refurbished to an 'as new' condition (see back cover photo). Budget quotations indicated that this would be too expensive and so we helped develop an alternative strategy.

Until the time of transfer, presses would be operating and so it was difficult for any potential contractor to assess the extent of work and give a firm price. It was therefore decided to let a separate package for the strip down and transfer so that the extent of the refurbishment work could be established once the presses had been dismantled. A firm price and programme for the work could also be agreed at that point.

Presses were scheduled to be released according to the time they were required in the new facility and our estimate of the transfer and refurbishment periods. Long delivery items, such as clutches (some had to be delivered from the USA), were ordered in advance.

Generally, the presses were dismantled and transported in four main components: crown, uprights, slide, and bed. The crowns were the heaviest, weighing up to 150 tonnes, and were placed in position by hydraulic lifts.

The tie rods which hold the whole press assembly together were threaded through the crown, uprights and bed before being tightened. The rods were then heated by internal elements and tightened again so that as they cooled, the assembly is pulled rigidly together. Where there was insufficient headroom caissons were constructed in the press foundation pits so that the rods could be inserted from below.

Our work on site ended with the basic commissioning of the presses. The client's team then managed the installation of robot and die change equipment and the overall control systems. Press lines were handed over as soon as they were completed so that the finishing and training operations could begin at the earliest opportunity; some lines went into operation whilst building continued. They, of course, needed to be carefully screened off to prevent dust getting into the machinery.

Conclusions

Despite the extended scheme stage, the project was finished slightly ahead of the original completion requirements, and within the budget.

Our team found the experience both demanding and rewarding, being responsible for every stage of the building process. They had to help shape and develop the client's views of his building needs and having done that, they had to meet those needs by selecting contractors and managing them within a programme and budget.

They were responsible for all aspects of their portion of the works.

The key features of the project management were as follows:

- Design and management by a single organization
- A well-thought-out definition of requirements which set the guidelines for the remainder of the project
- A flat management structure which made for efficient communication
- Managers who were fully responsible for delivering their part of the project to meet the client's needs within time and cost restraints
- Direct relationships between designer and work package contractor.

Credits
Client:
Venture Pressings Ltd.
Design, project, and construction management:
Ove Arup & Partners
Production engineering consultants:
Rossmore Warwick
Architectural consultants:
Harper Fairley Partnership
Photos:
6. Bryan Clifford
7. Nick McGreevy

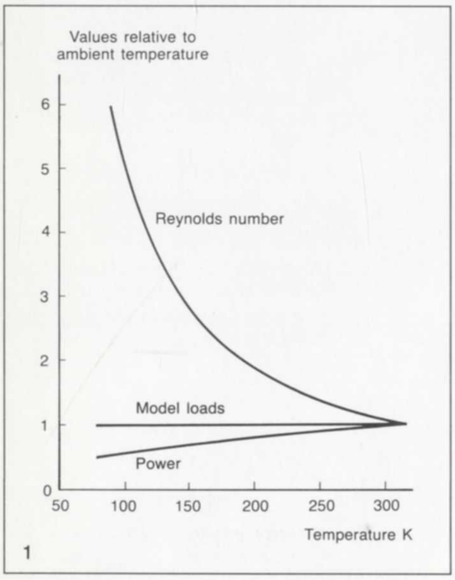
European Transonic Windtunnel

David Whittleton

Introduction

The primary aim of the European Transonic Windtunnel is to provide the European aerospace industry with advanced aerodynamic test facilities comparable with the best in the world. Windtunnels are, and are expected to remain in the future, a major source of aerodynamic design data. For new aircraft projects to be effective, test facilities must be capable of simulating actual flight conditions. The windtunnel test parameters, which need to match corresponding flight parameters, are the shape of the aircraft, the Mach number, and the Reynolds number. (It will be recalled that Reynolds number is non-dimensional, depending on the size of the model, the flow velocity, density, and viscosity of the air; it represents the ratio of inertial and viscous forces. Its value determines the type of flow regime, such as laminar, transitional or turbulent.)

In all modern windtunnels currently in use the first two parameters are normally simulated correctly, but the Reynolds number is lower than the correct figure for flight. The fundamental concept of the ETW is to increase the Reynolds number by reducing the tunnel airstream to a very low temperature. The combination of low operating temperatures and pressurization (4.5 bar) enables a six-fold increase in the Reynolds number as shown in Fig. 1. The lower temperature is obtained by a process of liquid nitrogen injection into the tunnel circuit.



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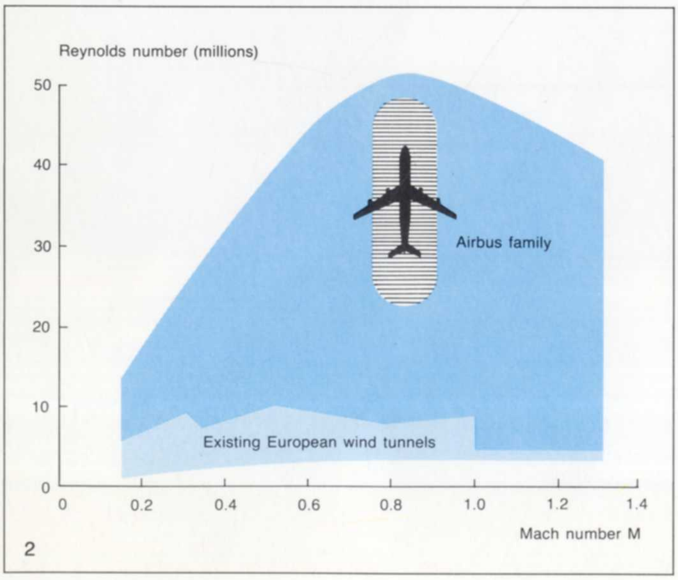


2

Background

The four contributing nations — Germany, France, Britain and The Netherlands — began discussions on the need for a high Reynolds number windtunnel in the early 1970s. The cryogenic, fan-driven concept was agreed in 1976, and a pilot ETW — a scaled-down version of the current project — was first operated in Amsterdam in 1984. By 1985, agreement in principle had been reached on the basic design parameters and the site, and it was decided to proceed to what was known as the functional specification stage of the project. For implementation, the client body decided to appoint an industrial architect (INA) to act as project manager, co-ordinator, auditor, and designer of some aspects of the project. Arups formed a consortium with firms from the other three contributing nations and the proposal which resulted was accepted by the client body in late 1986. The functional specification stage then began, and by early 1988 bid documents had been prepared for over 30 work packages and a detailed cost estimate was under consideration by the multi-national steering committee.

The Memorandum of Understanding for construction and operation was signed in mid-1988, and the project is now under construction and currently heading for completion in early 1993.

The ETW is located at Porz-Wahn, on the site of the German aerospace organization DLR, adjacent to Köln-Bonn airport.

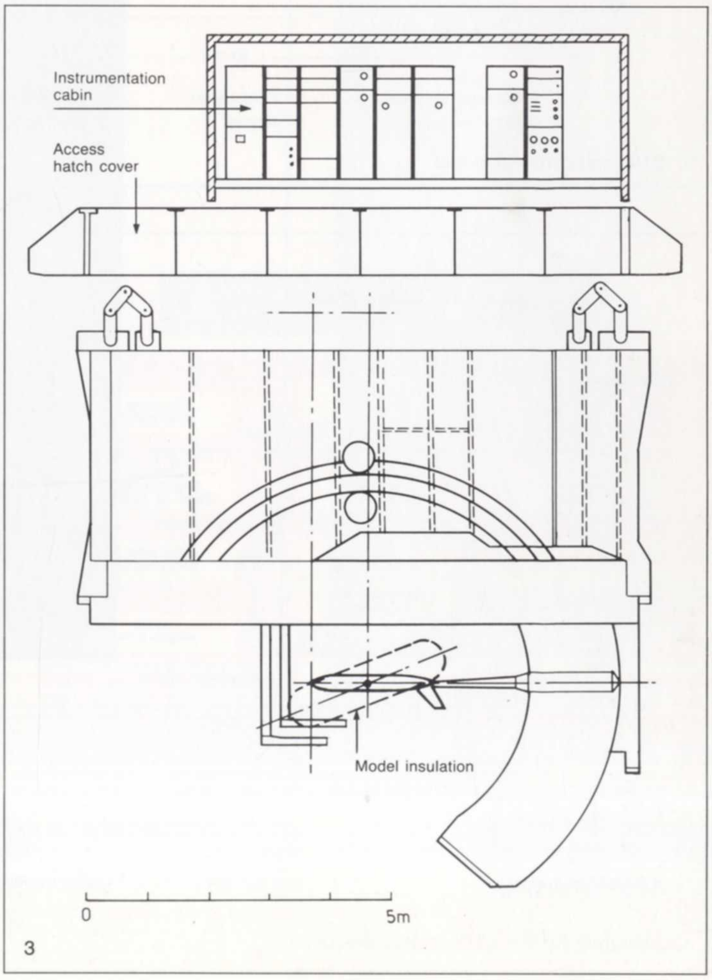
Technical description

The key specification parameters are given in Table 1. The test section configuration results from the requirement to achieve a Reynolds number of 50M at Mach 0.9, given a maximum pressure of 4.5 bar and a minimum temperature of 120K. The Mach number capability ranges from 0.15 to 1.3. Fig. 2 shows the performance envelope of the ETW and illustrates that the cruise conditions for the Airbus family of aircraft fall well within the facility's operating range. For most tests, the tunnel will be operated at high Reynolds numbers, making optimum use of the low temperature capability of the facility. In order to meet anticipated demand, the ETW is designed to be able to produce up to 5000 polars (testing sequences) per year. In order to achieve this, a modular design was evolved for building and handling aircraft models in a cryogenic environment. Models to be tested will be mounted on carts comprising the model itself, its support, part of the test section wall and pressure shell, and an instrumentation cabin (Fig. 3). Interchangeable model carts will be prepared for testing under ambient conditions, then transported through a dry air zone (dew point −70° C) into variable temperature check-out rooms to be thermally conditioned before installation into the test section. Sophisticated provisions are made to maintain pressure and temperature in the dry air hall, and to ensure economic operation and the highest possible level of operator safety.

Table 1: ETW specification parameters

Test — section dimensions	2.4m × 2.0m
Mach number range	0.15 – 1.3
Operating pressure range	1.25 – 4.5 bar
Operating temperature range	90 – 313K
Fan drive power	50MW
Productivity	5000 polars/year

1. Basis of the cryogenic concept.
2. ETW performance envelope.
3. ETW model cart.



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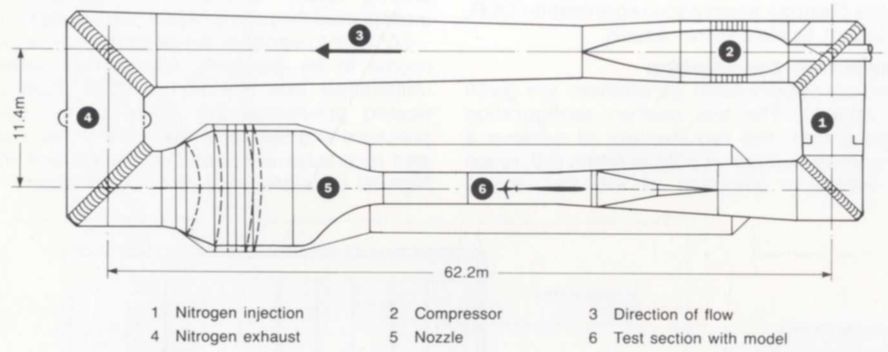
The aerodynamic circuit of ETW is shown in Fig. 4. The test section, which is the heart of the wind tunnel, is followed by a variable diffuser designed to prevent flow disturbance propagating upstream, and to provide Mach number control during tunnel operations. Liquid nitrogen injection, located just upstream of the compressor, is made through nozzles designed to provide uniform flow distribution and a minimum droplet size. The gaseous nitrogen exhaust system is located at the opposite end of the tunnel.

The pressure shell is of welded stainless steel construction, and because of the cryogenic environment and the temperature changes during tunnel operation, the pressure shell is internally insulated. The compressor is required to operate over a wide pressure, temperature, and speed range. It is a two-stage machine powered by a 50MW drive system, comprising a sychronous motor fed via a static convertor. The 4.5m overall diameter rotor blades are made of composite materials. Liquid nitrogen is injected into the circuit, to compensate for compressor heat, at a flow rate of up to 250kg/sec. It is estimated that some 75 000 tonnes of liquid nitrogen per year will be required when the ETW is fully operational. Initially, nitrogen will be supplied by road tankers, but space has been provided for the installation of a dedicated, on site, liquid nitrogen plant. Gaseous nitrogen is vented from the tunnel via a blow off system, terminating in a 50m stack designed to disperse the nitrogen gas into the atmosphere. A data acquisition system (DAS) will control the measurement of forces, pressures, temperatures, attitudes and positions through transducers in the model and in the wind tunnel. Satellite DAS computers contained in cart-mounted instrumentation cabins will convert measurements to digital form, and transmit the data to the main facility computer. Selected data will be converted in real time to enable test operators to apply intelligent control to the test programmes.

Project organization

The overall organization of the ETW project team is shown in Fig. 5. Essentially, ETW GmbH acts as the client and reports to a multi-national supervisory board. ETW GmbH has overall responsibility for the technical specification and operational characteristics of the windtunnel, and its team includes technical experts from aerospace research establishments in each contributing nation.

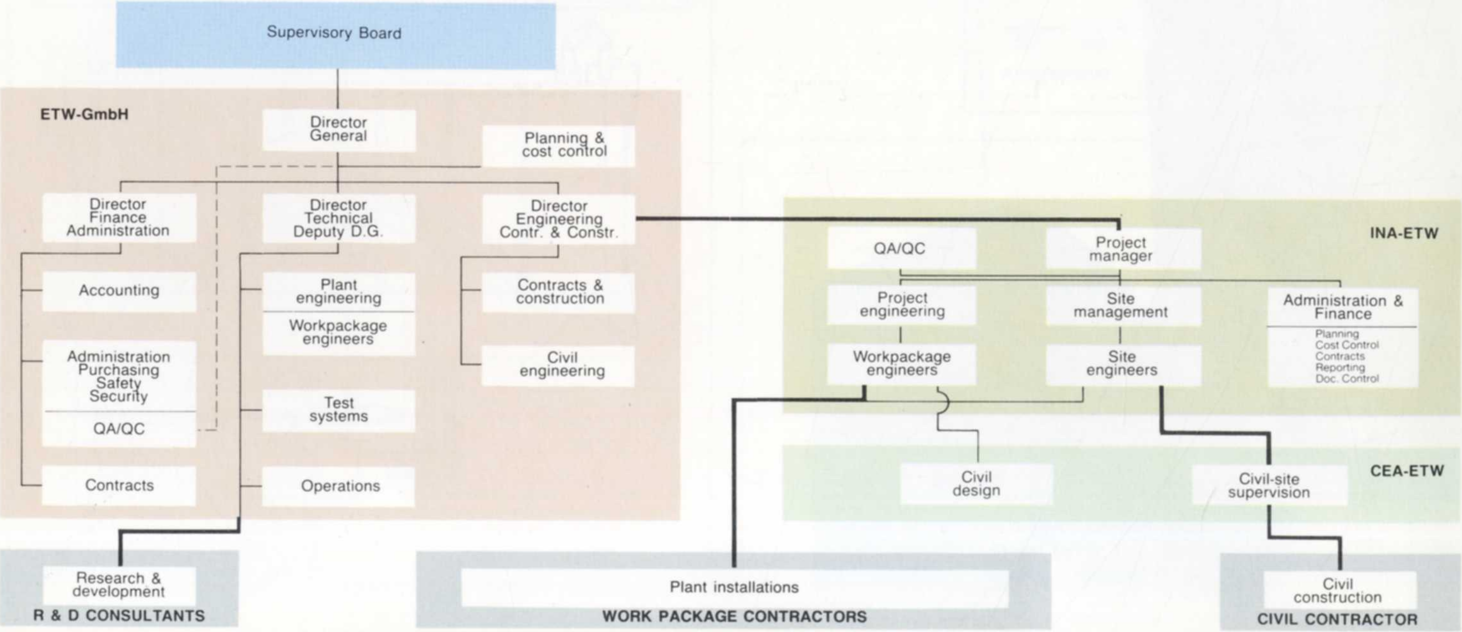
The INA consortium acts as the client's project manager and handles each of the work packages from initial bidding through to detailed design, procurement, construction, and supervision. Civil and building work detailed design has been carried out by the Lahmeyer Consortium (CEA) acting under the management of the INA. A work package breakdown is given in Table 2.



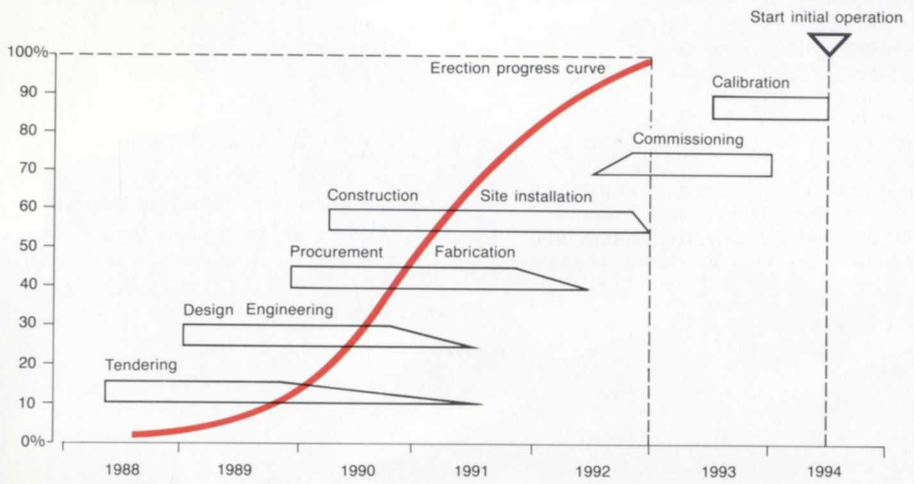
4. ETW aerodynamic circuit.

Table 2: Breakdown of overall ETW plant

Work package	*Title*
01	INA-ETW Project Management
02	Temporary Site Services
03	Buildings and Associated Services
04	CEA Services: Building Design and Civil Site Supervision
06	Remotely Operated Doors
08	Pressure Shell and Fixed Internals
09	Electrical Design
10	Electrical Supplies
11	Power Transformers
12	Medium Voltage Switchgear
13	Low Voltage Switchboards and Motor Control Centres
14	Emergency Power Supplies
15/29	Electrical and Control Cabling and Installation
16/17	Compressor and Drive System
18	Contraction, Plenum Internals and Model Carts
19/07	Nitrogen and Dry Air Systems
21	Oxygen deficiency monitoring
24	Software for Main and Auxiliary Control Systems and for Monitoring and Management Systems
25	Data Aquisition and Reduction Systems, Test Instrumentation
27	Computer Hardware
30	Optical Systems (Test Section and TV Systems, other TV Systems, Flow Field Observation and Surface Flow Visualization Systems, Model Attitude and Deformation Measurement Systems)
31	Balance Calibration Systems
32	Operating Manuals
33	Pilot ETW Modification and Installation
36	Equipment for Offices, Laboratories, Workshops
37	Cryogenic Model Handling System, VTCR Equipment



5. Organogram for the ETW project execution.



6. Construction schedule.

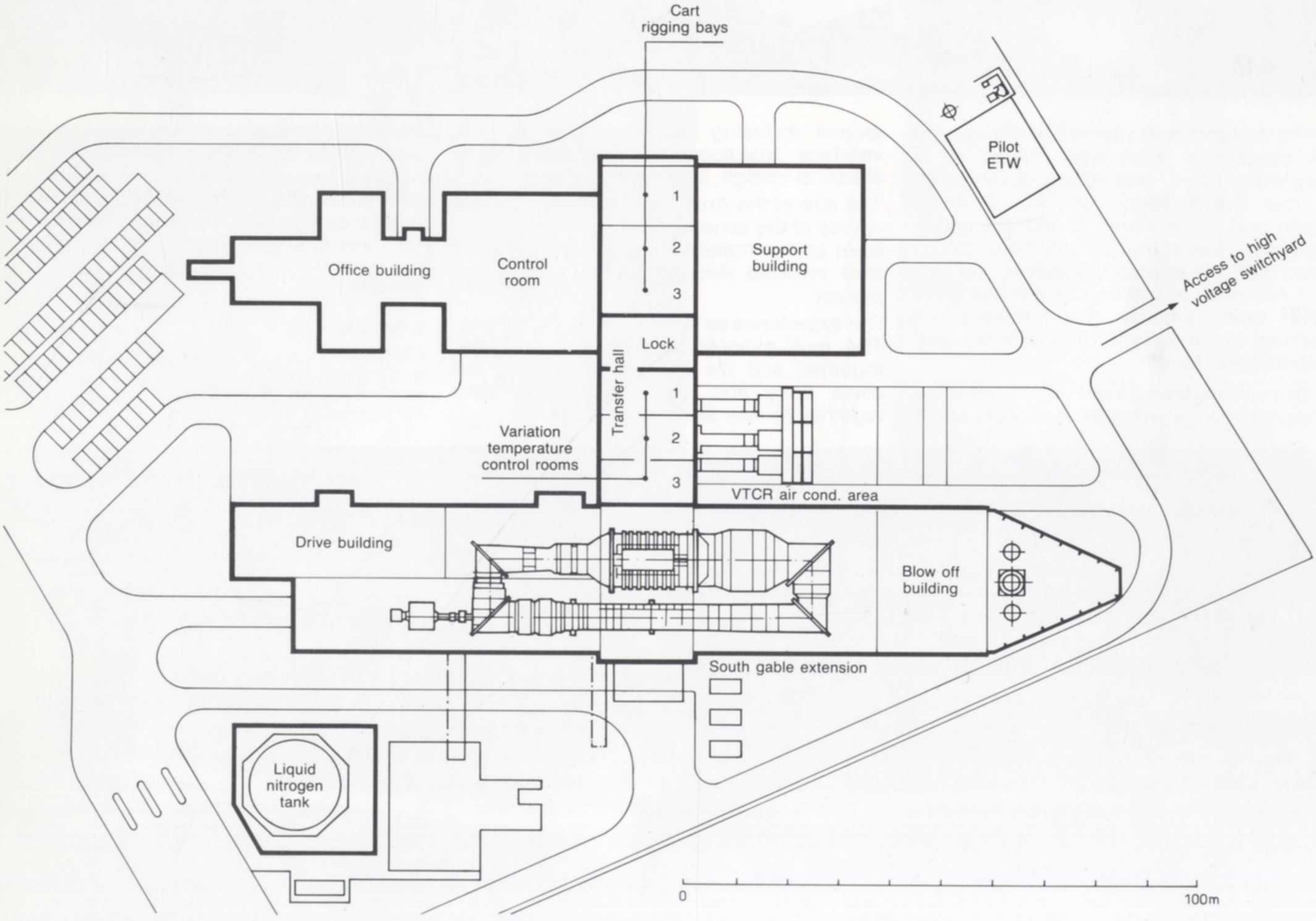
Construction schedule

An outline of the overall design and construction programme is given in Fig. 6. At the time of writing, the project is on schedule, and all major work packages have now been let.

Financial aspects

The costs associated with the procurement and construction of the facility, planned to last until the end of 1994, are shared by the contributing nations in the proportion of 28% each for France and the UK, 38% for Germany and 6% for The Netherlands. A budget ceiling of DM640M, at end 1989 prices, has been authorized. The project cost estimate is continually maintained and updated. Cost control is executed on a daily basis, and reported to ETW GmbH management. To date, some 75% of the funds allocated have been committed to contracts.

8. Construction in progress, September 1990.



7. Building plan view.

The Consortium

Arups are a part of the INA-ETW Consortium, which comprises the following firms:

Interatom GmbH
Friedrich-Ebert-Strasse,
5060 Bergisch Gladbach 1, Germany

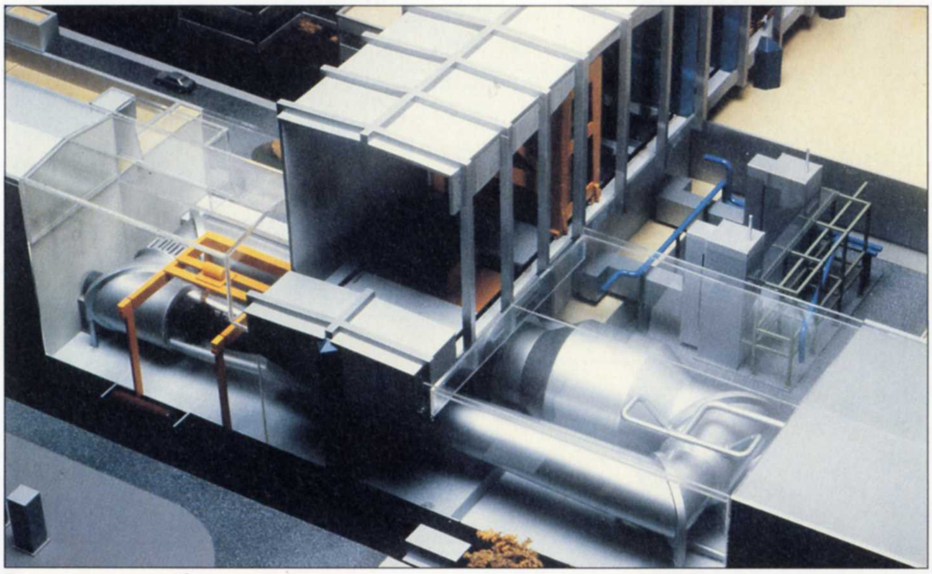
SGN
Societé Generale pour les Techniques Nouvelles
F-78182 Saint Quentin Yvelines Cedex, France

Sessia SARL
3 rue Jules Guesade, F-92300 Levallois, France

Ove Arup & Partners International Ltd.

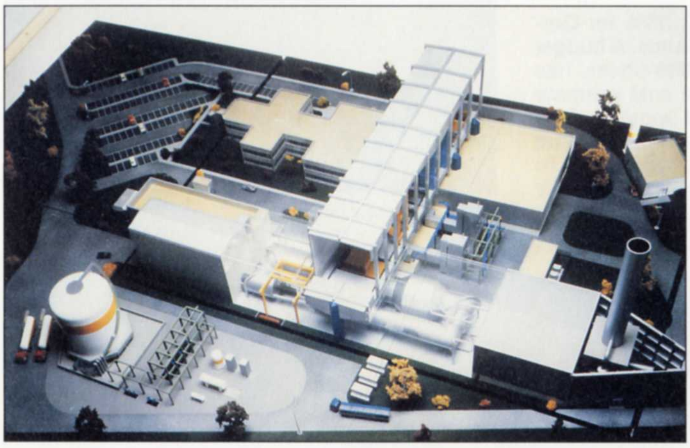
Comprimo
Post Box 4129, 1097 DL Amsterdam, The Netherlands.

9. Model showing tunnel circuit.
10. Cutaway model of complete facility.
11. Construction in progress, May 1990.



9△

10▽



11▽

During the functional specification stage, the INA consortium work was divided on a disciplinary basis, with Arups dealing with the civil and building work, the electrical design and some planning and estimating functions. Since the commitment to go ahead with construction, however, the INA team has been based on site with the ETW GmbH team, and the INA functions are executed on the basis of a fully integregated, multi-national team.

Arups currently have 14 staff seconded to the consortium, engaged in most aspects of the project including planning, cost control, interface management, mechanical and electrical design, and supervision.

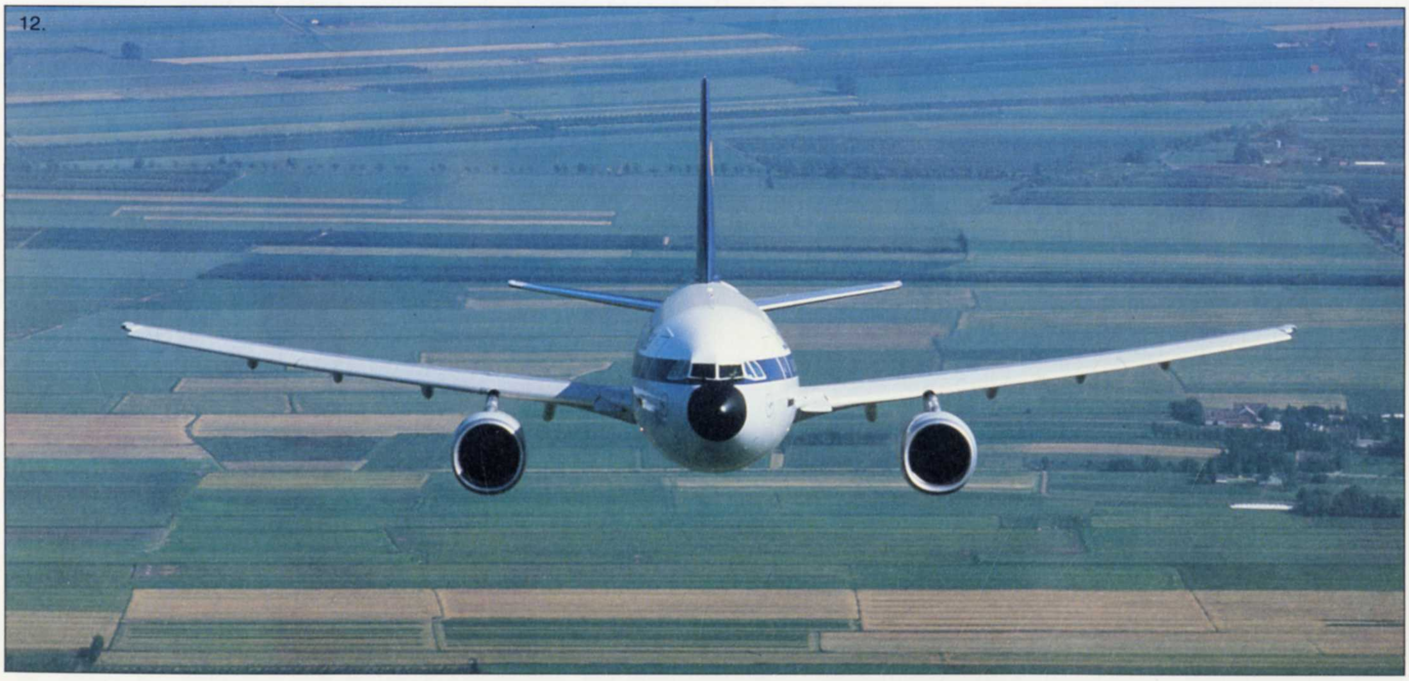
The size of the Arup team will vary over the course of the construction, but we expect to have approximately the present number of staff involved through to the end of the project.

Our experience so far has been a happy one. The multi-national team works very well together, and the benefits of locating the client body and the Industrial Architect together on site are now obvious.

With the individual work packages also being provided by contractors from all four participating nations, the project is genuinely a joint effort, and if completed on time and on budget as expected, it will stand as a magnificent example of European collaboration.

Credits
Client:
ETW GmbH
Photos:
8, 11: Brian Marriott
9, 10: ETW (Mr. Peter Droste)
12: Lufthansa

12.



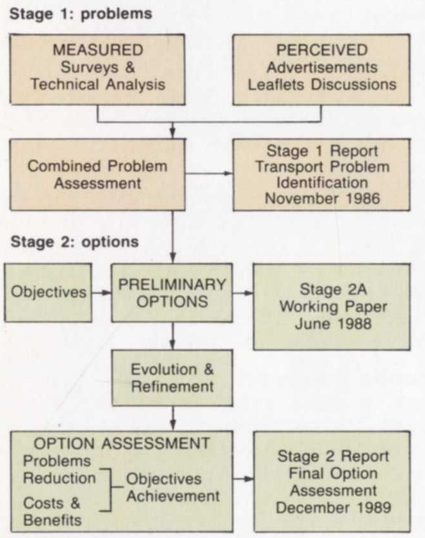
The East London Assessment Study

Terry Hill

Transport in London

Transport in London is a controversial topic. That this is a truism can be judged from the progress of the East London Assessment Study. It was commissioned by the Department of Transport in late 1984 to identify transport problems in an area of inner London, and propose options for solving them. It started as a road assessment study but we immediately saw, and had our client accept, that it should encompass all forms of transport. The study was completed by the end of 1989, yet although the issues are now clear-cut, the solutions are as elusive as ever.

Transport in large cities is controversial because the demand for all forms of transport infrastructure almost always exceeds the supply. Whatever the policies or investment attitudes of governments and local authorities, no huge city (say with a population of three million or more) has yet found the way to improve satisfactorily urban accessibility. Roads and railways are congested and overcrowded, road accident statistics are horrific, and noise and air pollution levels caused by traffic are both resented and possibly harmful. Finally, no city's public transport system pays its way.



1. Study approach.

Transport plans

London, like most huge cities, has had its grand and integrated transport plans, usually associated with a city-wide land use strategy: Where should industry locate? How much new housing will be necessary? How many strategic commercial and retail centres are needed? At various times, and to satisfy various needs, London has sought to deal with its problems by siting new towns on its periphery, building a series of Ringway roads and, in the 1970s, confining major new developments to those locations with adequate transport connections.

The present government took the view that these 'grand plans' had not been effective because they were indeed too grand. No government or planning authority could ever achieve the plans' objectives in a reasonable time, and in any case public bodies were probably not best placed to plan what London as a whole needed. Therefore, in rough order of events, the government:

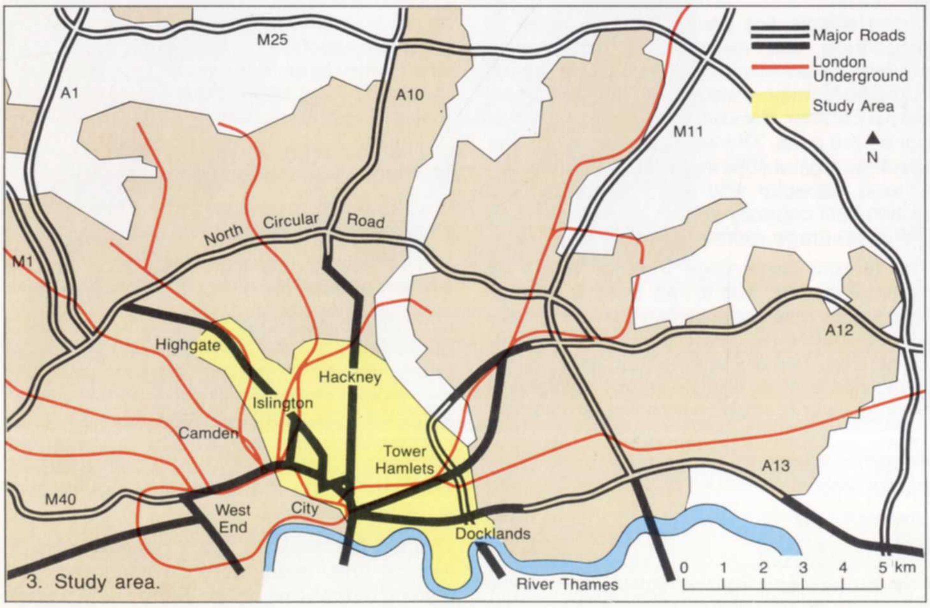
(1) Transferred control of London Transport from the Greater London Council to central government, and separated it into its constituent operating units (essentially London Underground Ltd. and London Buses Ltd.).

(2) Established the London Docklands Development Corporation to regenerate this derelict area by removing most planning controls.

(3) Abolished the Greater London Council which, amongst other things, was London's strategic planning and transport authority.

(4) Replaced the substantial and statutory Greater London Development Plan 1976 with the slimmer and more *laissez-faire* Strategic Planning Guidance for London.

It was therefore in keeping with this attitude of rejecting 'grand plans' that the Department of Transport established four London Assessment Studies, each located in an area of acute transport problems, and each charged with identifying the precise nature of the problems, and then the options for improving the area as a whole.



3. Study area.

The East London Assessment Study Area covers just over three of London's 32 boroughs, contains a population of about 500 000 people, and is located in the sector of London situated between the central financial and commercial core and outer suburbia. It can be classified as inner city and, in the late 1970s and through the 1980s, lost a third of its manufacturing jobs, reached London's highest unemployment rates, but then benefited from the later economic upturn by being on the fringe of the City and including London's Docklands.

The study process

There were no established procedures for studies such as this one, and the methods which we used therefore had to be innovative. For instance, the study process was designed to be responsive to transport needs and people's attitudes; probably more so than in any previous transport investigation. It was responsive in three ways:

(1) Problems for transport, and caused by transport, were identified and analyzed in a level of detail never attempted before, and this Stage 1 phase was conducted prior to and independent of any thought being given to new options. There were, therefore, no preconceived ideas.

(2) Objectives were set jointly by the Department of Transport and the local authorities, again with no reference to the means of achieving them. Arups took no part in formulating the objectives which stated that options should:

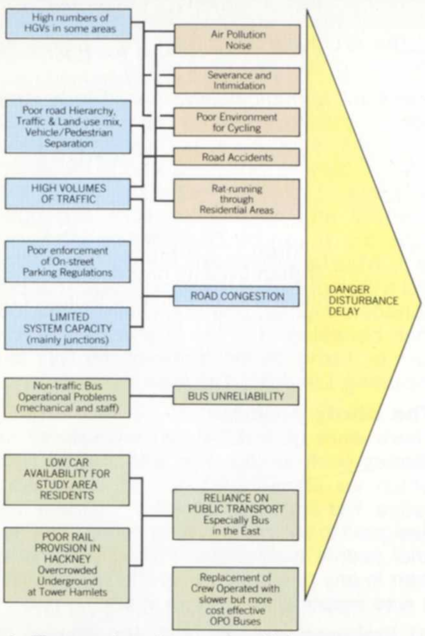
- Promote accessibility
- Support employment, economic growth, and regeneration
- Develop an efficient transport system
- Improve the environment
- Enhance safety.

(3) Public involvement was built into the process from the outset. As well as getting reactions to two reports and a working paper at key stages, the public helped by having virtually continuous contact with the study team. In the Problem Identification stage the 'measured' technical analysis was conducted in parallel with 'perceived' understanding of problems.

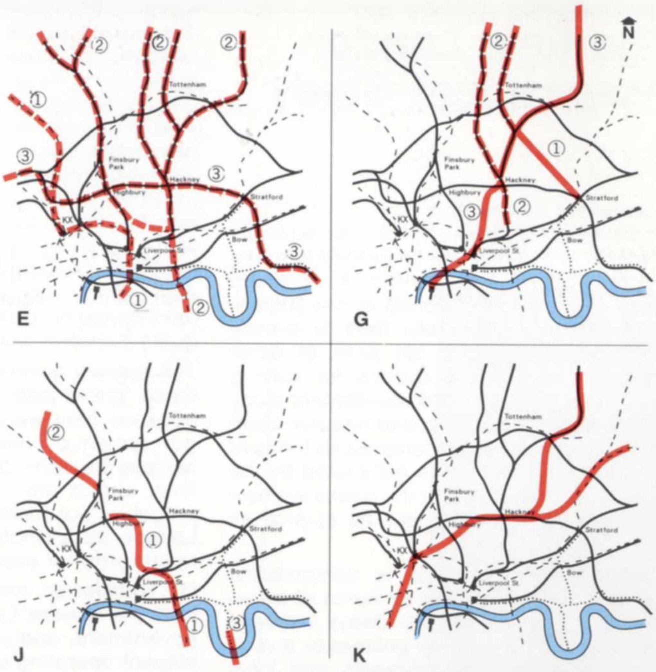
- Advertisements were placed in local and regional newspapers.
- 200 000 leaflets were delivered to households.
- 535 local groups were written to and 47 came to the study office.
- 104 businesses were interviewed.
- Drivers were interviewed at 18 locations.
- 32 'discussion groups' were held, made up of people randomly selected to fulfil designed quotas of age, sex, car ownership, race, socio-economic status and area.

The consultation, although not representative in a statistical sense, was thorough and ensured that all sections of the community had a means of expressing their views, and that no problem would be omitted.

The Department of Transport's brief for proposing options (packages of schemes and measures for public and private transport), gave us a free hand to explore all conceivable ideas but we were to confine ourselves to the Study Area, and to existing government policies. These restrictions were perhaps unfortunate since there were consistent requests from the public, local authorities of all political parties, and from professionals, that London-wide issues and policies relating to public transport, company car subsidies and traffic restraint should all be addressed.



4. Transport problems: key linkages.



5. Preliminary rail scheme tests.

Problems

There was no doubt that the Study Area — Tower Hamlets, Hackney, Islington and the Highgate/Archway area of Haringey — suffered from wide-ranging and severe transport problems. This conclusion surprised nobody, but we quantified and revealed how problems linked together and reinforced each other in particular ways.

High volumes of traffic and limited road capacity, coupled with poor enforcement of parking regulations, were to blame for road congestion. This was severe throughout the Study Area but was at its worst in the western parts, in Islington. All road users suffered but it was particularly acute for those who had least choice in the journeys they had to make or modes of transport they had to use.

Local and through traffic used the same roads and there were few clearly defined routes for longer distance traffic. There was therefore a lack of segregation between local journeys and those which passed through the area. Many roads were also the location for shops, hospitals, offices and other facilities which attracted large numbers of people. This resulted in conflict between traffic and pedestrians and severely affected the environment of people who lived or worked in the area.

Car ownership was low, only 1 in 3 Study Area households had access to a car, compared with the London average of 1 in 2. This inevitably meant a heavy reliance on public transport for local residents. But public transport itself was deficient. Half the Study Area had no Underground service and its BR service was not designed to offer a substitute; so people relied on buses. Yet buses were of course affected by the same road congestion as other road users, which with other operational problems, caused bus service unreliability.

Overloaded streets and the poor bus service: from these two issues stemmed a whole series of other problems. Noise and air pollution levels were high: a direct result of dense traffic flows. Heavy lorries were significant contributors to these nuisances, and resented as such.

Public v. private transport

Is there genuine choice in deciding whether to invest in public or private transport? Most of the people commenting on the East London Assessment Study asserted that efficient and attractive public transport would solve the problems and that, in any case, increasing road capacity would only increase traffic volumes, leaving congestion as bad as ever.

Forecasting the effects of a major transport scheme is concerned with predicting the sum of people's individual travel decisions, and this means understanding human behaviour. It is therefore to a certain extent unpredictable. If an increase in capacity is provided on a congested transport corridor, this much is known:

(1) Travellers will change route between the same origins and destinations to take advantage of shorter or quicker journeys. This reassignment effect can influence route choice over a wide area.

(2) Travellers will travel at different times, starting journeys later to arrive at the same time. Peak contraction is the converse of peak spreading, which is apparent in most parts of London, particularly the centre.

(3) Over a period of time people change their origin or destination, their home or place of work for example. This redistribution of trip ends is still related to changes in existing journeys.

(4) Travellers switch to the upgraded form of transport. This modal transfer between public and private transport requires people to abandon or start using a car.

(5) Totally new journeys are made for totally new purposes — trip generation.

These effects are given in rough order of magnitude, with reassignment dominating the rest. To solve road problems by investing in public transport would require substantial modal transfer. We concluded that this would not be the case. The forecast modal transfer resulting from a 40% increase in total Underground capacity and a 22% increase in British Rail capacity across London is given below (average morning peak hour).

The largest percentage transfer would be sub-modal, from bus to rail, but the relief of road congestion caused by massive investment in public transport alone would hardly be noticed. The low transfer is due to people being tied to their chosen mode because of owning a car or making a particular journey.

All public transport	+ 2.8%
British Rail	+ 4.4%
Underground	+ 7.3%
Bus	– 3.8%
Private cars and light vehicles	– 1.2%

The converse effect, of massive investment in road capacity, was investigated and this suggested similar but smaller modal transfers, less than 1% increase in private vehicles. Roads are different from railways, however. If more passengers try to use an already overcrowded train, it will still travel at roughly the same speed. The primary effect is increased discomfort and possible danger on overcrowded platforms. If more traffic tries to use an already congested road, delays increase disproportionately.

It therefore seems likely that in areas of severe road congestion the effect of modal transfer (and possibly trip generation) resulting from major highway capacity increases could undermine the economic benefits that the investment was meant to produce.

The message seems to be that investing in only one kind of transport system would not be sufficient: that investment must be across the whole range of transport modes.

Public transport

East London's rail network has never served it well. Central, north and west London have a well-developed Underground network, and south London's BR services, whilst unsatisfactory in their complexity, at least have a good coverage. East London is skirted by six Underground Lines (Northern, Victoria, Piccadilly, Circle/Metropolitan, Central and District) and is penetrated by three BR outer commuter services (into Kings Cross/Moorgate, Liverpool Street and Fenchurch Street) which carry large numbers of people through the Study Area rather than serving it. Three major investments were needed:

- The long-standing unreliability of the Northern Line needed to be solved.
- The chronic overcrowding on the Central Line needed to be relieved.
- The lack of any significant mass transit system in Hackney needed to be addressed.

Our preliminary options suggested major upgradings of the Northern and Central Lines, including new high-performance rolling stock, resignalling and better power supplies. We had worked closely with London Underground Ltd. and, following the publication of the Stage 2A working paper, they authorized the necessary expenditure for these schemes.

This left the Hackney 'gap'. Several ways of serving this area were investigated, including extensions of the 1880s East London

Line northwards and the BR turn-of-the-century Waterloo and City Line ('the Drain') northwestwards, possibly as light rapid transit schemes. Busways, where buses run in exclusive rights of way, were investigated as a method of insulating them from the effect of general road congestion. Although most of these schemes had merit, and indeed the East London Line extension is being actively pursued by London Transport, only a full new Underground line would provide the required level of service. Because of high cost and capacity, an Underground line would have to serve an area greater than the Study Area alone.

A new Underground route was devised to pass through an unserved area of west London as well as east London and to take over existing branches at its extremities.

Called the Chelsea-Hackney Line and based on an earlier proposal, it was found to perform extremely well. On some tests (using a London-wide multi-modal computer model), it was forecast to carry more passengers than any existing Underground line.

Other, more modest rail schemes were identified and carried forward but for bus services we concluded that, in general, their routes were not the issue; their performance was.

Bus lanes have been implemented which attempt to give priority to buses over other traffic in peak periods. They are rarely observed and so bus reliability is a hostage to general and severe road congestion. We proposed a package of measures:

- Variable message bus lane signing to emphasize their operation
- Visible camera/video equipment to deter/record bus lane violations
- Detailed reviews of bus lane and bay layouts
- Selective Vehicle Detection at traffic signals to give priority to buses through junctions (since authorized).

These measures, with the rail schemes, would solve all or most of the public transport problems of the area.

Road schemes

Road construction and traffic are, and are perceived as being, more environmentally damaging than rail schemes and trains. Rail is obviously more efficient at transporting large numbers of people to concentrated destinations but it cannot cater for the dispersed pattern of trips like private transport (cars, commercial vehicles and cycles). London in general, and the Study Area in particular, has a long history of opposition to new roads. Nevertheless there was already a substantial programme of highway investment in and around the Study Area.

The M25 London Orbital Motorway has removed most unnecessary through trips, particularly heavy goods vehicles, and a number of schemes along the A405 North Circular Road will mean that by the mid-1990s there will be a second high capacity orbital route for North London. In the south of the Study Area, the Docklands Highways were being promoted by the London Docklands Development Corporation. These were designed to cater for the huge growth in employment in this area and they would allow relief and improvement of the A13.

So the highway problems resolved into those for road users in the western part of the Study Area, and those caused by road users through the Study Area, particularly in residential parts. A major programme of highway link appraisal (using one of the largest highway network computer models ever built), showed that singly and in combination, radial links replacing or supplementing the A1 and orbital links located close to central London most benefited road users. It also showed that road building would not attract traffic out of the residential areas currently suffering from high volumes of through traffic. Ways had to be found of dissuading drivers from using side roads as short cuts (rat-running).

Traffic calming

Accepted traffic management techniques aimed at removing through traffic from unsuitable areas are crude but effective. They include road closures, banned turns and one-way streets. Because they are indiscriminate, these types of measures also deter those road users who have a genuine need to be in an area as well as those who are just passing through. They reduce local accessibility because they are 'all or nothing' and do not influence the way people drive.

Traffic calming seeks to change the priorities in the design and use of street space to influence route choice in a graduated way, and to improve road safety. The function of a street should be apparent from its whole design rather than from its prescriptive signing. The elements of traffic calming are operational and visual:

- Road alignment and sight lines
- Road and footway widths
- Vegetation, planter boxes and bollards
- Pedestrian 'capes' and crossings
- Parking bays
- Bus stops and lanes
- Cycleways
- Surface texture and colour.

Detailed case studies illustrated what was possible and traffic model testing confirmed that widespread relief from the impact of traffic could be secured by traffic calming, whereas it couldn't by building new roads.

Options

The principles of our options were very simple but had been established through thorough analysis:

- Rail schemes reduce rail problems (but not road problems).
- Road schemes reduce problems for road users (but not for those who suffer their environmental impacts).
- Traffic calming reduces the environmental impacts of road traffic in residential areas.

We concluded the balance of investment should be:

Rail schemes	£2000M
Bus priority measures	£5M
Road schemes	£200M
Traffic calming measures	£60M

Most of the rail scheme costs would be spent outside the Study Area because many parts of London would be served.

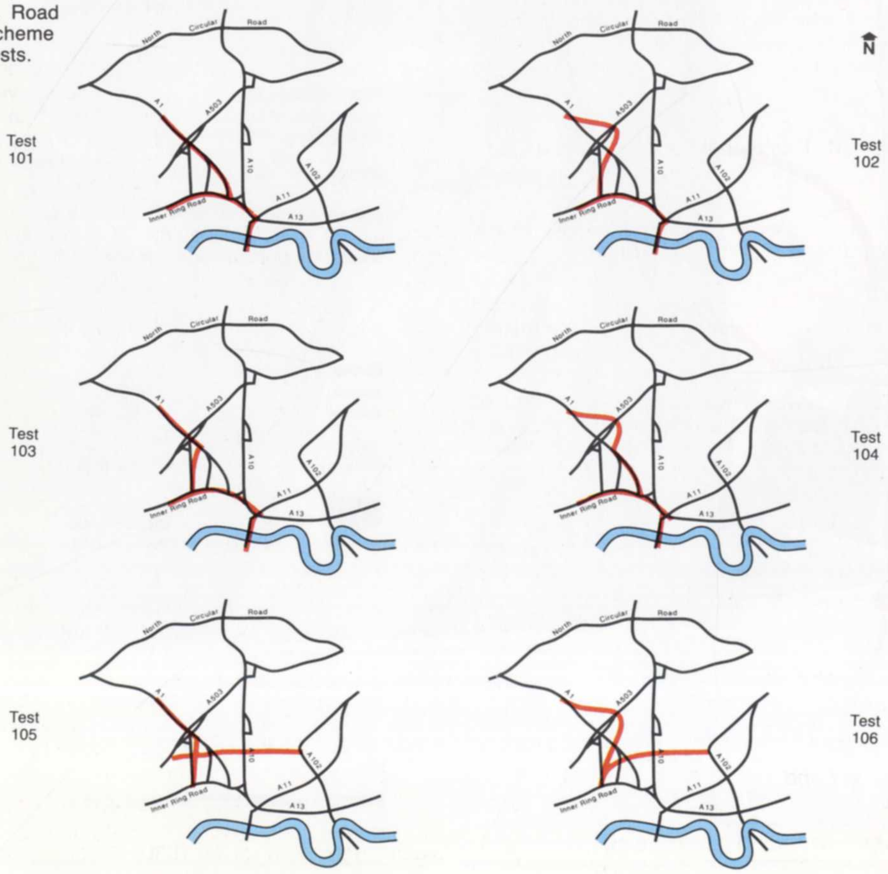
Conclusions

In London, it is relatively easy to demonstrate that a road scheme is economically viable but it is virtually impossible to convince people that road building is worthwhile. On the one hand car-ownership rates are growing dramatically, particularly in the low car-owning areas of inner east London, whilst on the other hand, attempts at trying to satisfy the demand for private transport are fiercely resisted. The situation for rail schemes is the converse. Current government criteria require the travelling public's 'willingness to pay' be tapped. These fare revenues plus private sector contributions have to be maximized. Therefore justifying rail investment is difficult but the idea of large-scale public transport investment is popular.

The Department of Transport's initial views on our findings were that:

- If nothing more is done beyond existing transport programmes for the Study Area, conditions will get much worse.
- Immediate improvements should be sought through tougher parking restrictions with better enforcement, and more traffic management schemes.
- Better parking enforcement and traffic management will not provide sufficient relief for the long-term.
- Some problems would be relieved by improvements to the public transport system.

6. Road scheme tests.


Test 101
Test 102
Test 103
Test 104
Test 105
Test 106

- Improving public transport cannot by itself solve the traffic and associated environmental and economic problems.
- Some improvements to the main road network are needed.
- New road capacity provides the opportunity for the traffic calming measures on adjacent local roads.
- Road improvements will significantly reduce accidents and enhance safety.

They also supported our view that road improvements should be linked to a comprehensive package of traffic calming measures.

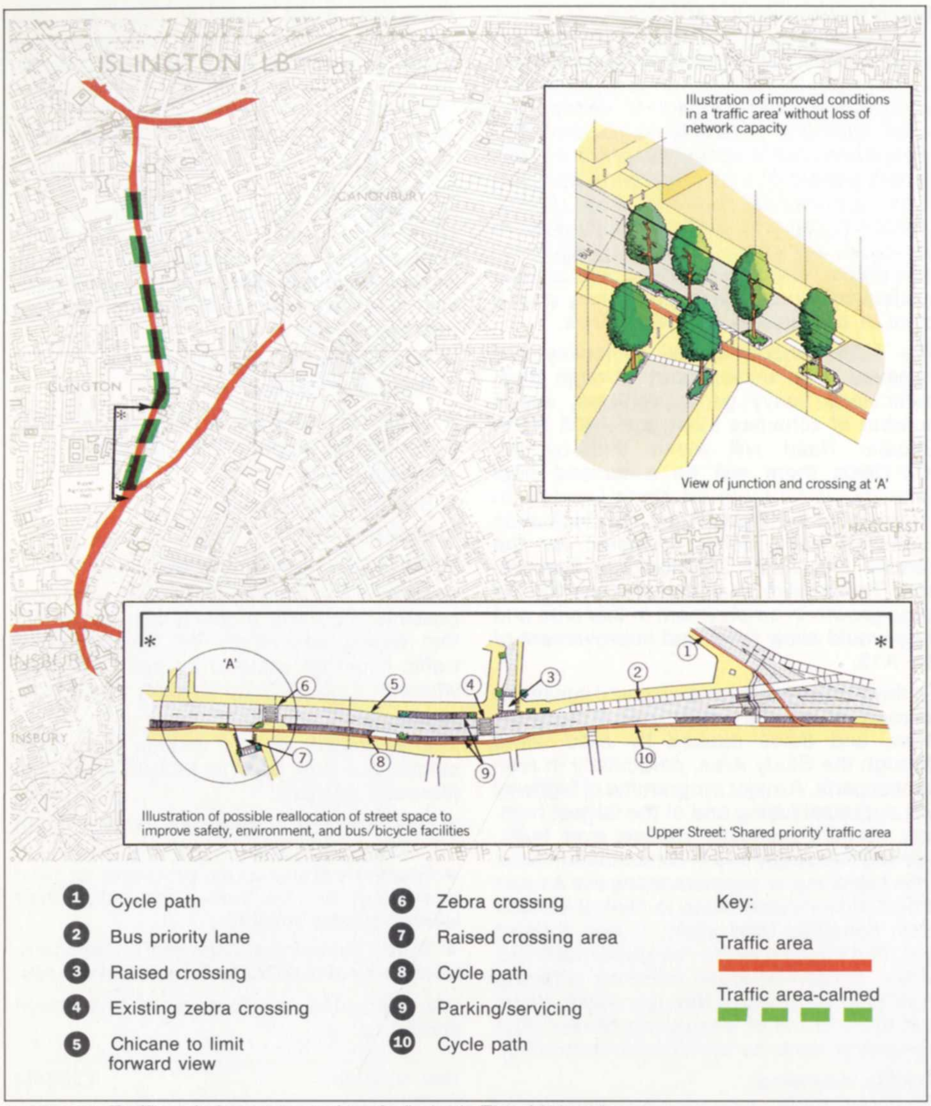
Following widespread public comment on our work, the Department's then Secretary of State, Cecil Parkinson, decided that:

- All the rail schemes will be considered further by the transport operators (London Transport and British Rail).
- Major road schemes will not be proceeded with.
- Modest road schemes will be carried forward.

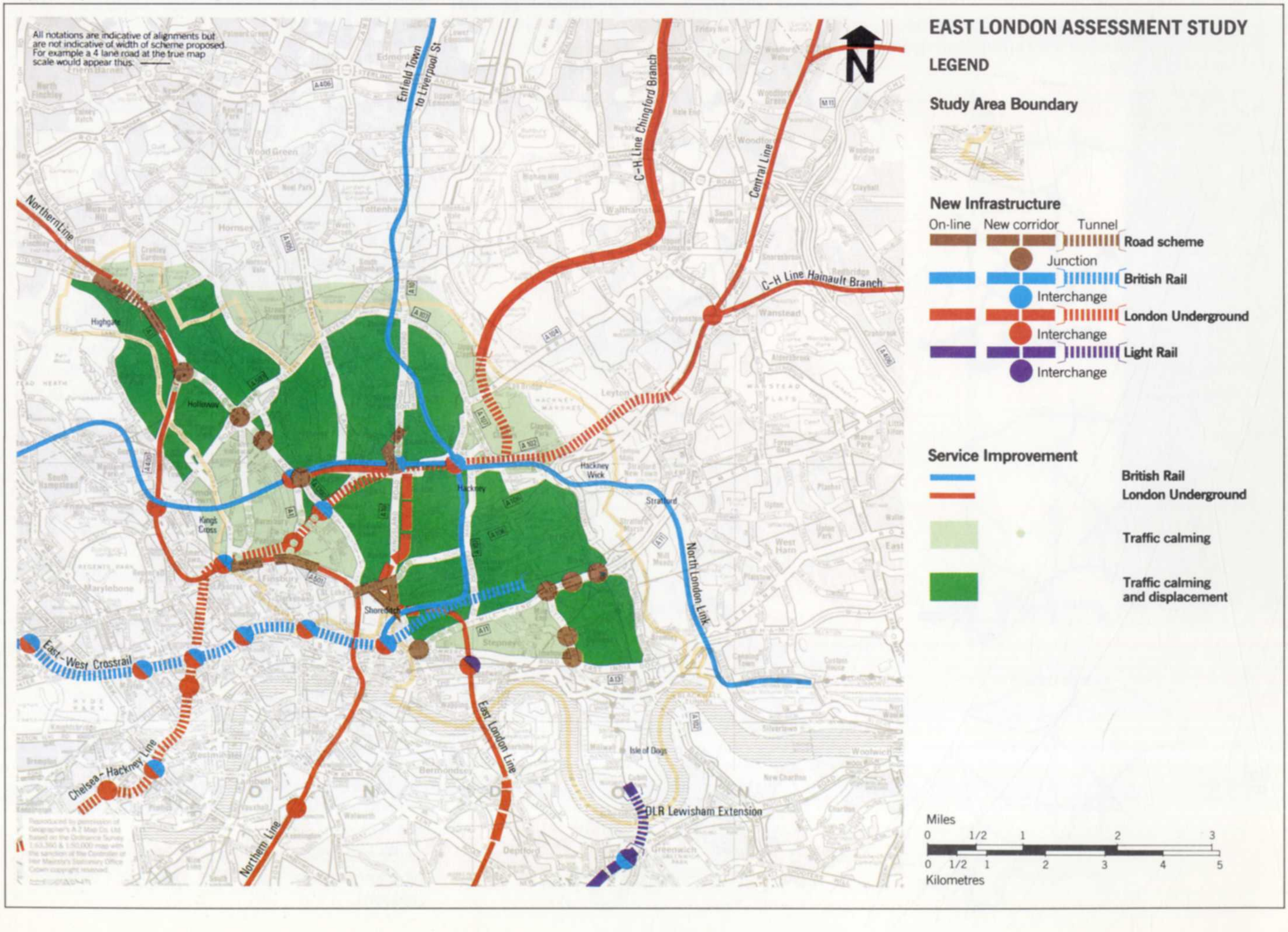
This, as a package, largely corresponded to the third of our better performing options.

Credits
Client:
Department of Transport
Transportation consultants:
Ove Arup & Partners
Sub-consultants:
Llewelyn-Davies Planning
Derek Lovejoy & Partners

Footnote:
In parallel with the Department's programme for transport schemes in London, they have proposed a Priority Route Network of roads. These will be subject to a series of special controls aimed at helping traffic movement and increasing capacity. Ove Arup & Partners have been appointed to implement a pilot project for an initial section of these so-called 'Red Routes'.



7. (above): Traffic calming case study. 8. (below): The third option.



The refurbishment of the Royal Hong Kong Jockey Club

Architect: Robert Matthew, Johnson Marshall & Partners

David Vesey Robin Forster Paul Suett

Introduction to the project

Horse racing, traditionally a very popular sport in Hong Kong, yields an average annual income of HK$34bn to the Royal Hong Kong Jockey Club (RHKJC) and a significant revenue income to the Hong Kong Government. The racecourse at Happy Valley is the older of the two courses owned by the Club and had shown a declining attendance in recent years, largely attributed to the inadequacy of the old facilities (Fig. 1).

In February 1987 the RHKJC decided to implement a programme of work for the renovation of the grandstands, and a team of consultants was assembled under the guidance of their project management. One of the major planning constraints was the time factor. Major demolition and refurbishment could only be carried out during the annual off-racing season between June and September. A total of four working phases were thus planned and carried out from June 1987 to September 1989 (Fig. 2).

The brief and programme

The main objective was to provide upgraded facilities in the public stands which would accommodate the full attendance capacity at all race meetings held in Happy Valley. The principal aims were to ensure that the licensed capacities could be handled; to eliminate overcrowding (the principal source of discomfort); to improve public facilities; and to provide more race viewing areas.

In order to maintain near-normal operation during the season, physical constraints were imposed upon the project as follows:

(1) Deep structural beams ran across the public stands from front to back, preventing public services distribution along the buildings.

(2) Additional floors and the new roof structure for the public stands were to be built on the existing foundations and main structural frame of the building.

(3) Refurbishment work had to be performed on slightly disparate buildings dating from the early '50s.

(4) Works scheduling was crucial: each phase had to be completed on time and facilities had to be continually available.

It was decided from the outset that, because of the multi-phasing and the demanding design and construction programme, an administrator would co-ordinate the engineering design work with the client, design team and contractors by attending all meetings, disseminating all information received and issued, and co-ordinating the production of information internally.

Structural engineering

Outline

Phase 1 included a lightweight profiled steel roof on steel frames over self-contained modules for betting booths, plantrooms, catering and security facilities, founded on pad footings and a new ground-bearing slab. Phase 1 was designed and constructed in only 22 weeks.

Phases 2, 3 and 4 involved extensive refurbishment and additional structure to existing buildings. Specific architectural requirements were for an elegant and uniform roofline and partial cover over the stands, extending from public block P2 to members' block M3. The structural systems had to respect the constraints of these existing buildings as well as provide an integrated framework for the architecture and extensive services requirements.

Phases 2A and 2B involved the complete gutting to bare reinforced concrete frame and addition of new plantroom floors and hanging rear stairs to public blocks P1 and P2 respectively.

In Phase 3, additional rooftop space for plantrooms, plus press and broadcasting facilities, was created. New steel structures were placed at existing roof level, necessitating complex structural strengthening of the existing reinforced concrete frame.

Phase 4 included two-storey lightweight steel roof frames for plantrooms and daylet boxes, with two new rear service ducts extending behind the building line for vertical services distribution.

Blocks P1 and P2

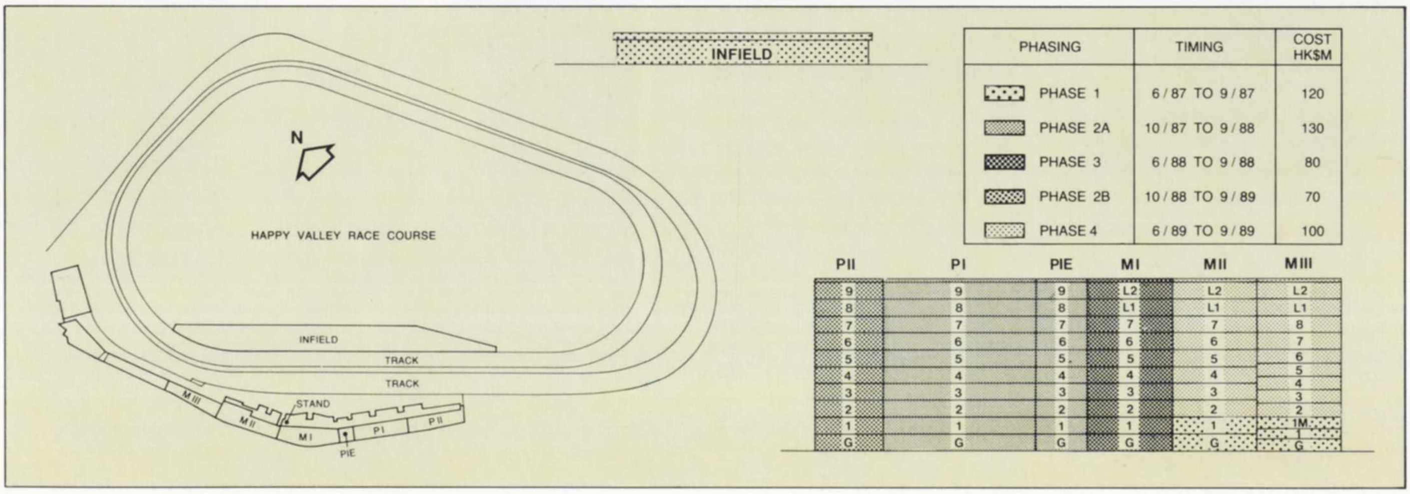
Existing structure

P1 and P2, 30m high and about 70m and 40m long respectively, are separated by an expansion joint. The building is about 14m wide, increasing to 27m at the lower terraced

1 ◁

1. Happy Valley racecourse.
2. Plan and working phases.
3. Racing in progress.

2▽ 3△



PHASING	TIMING	COST HK$M
▨ PHASE 1	6 / 87 TO 9 / 87	120
▨ PHASE 2A	10 / 87 TO 9 / 88	130
▨ PHASE 3	6 / 88 TO 9 / 88	80
▨ PHASE 2B	10 / 88 TO 9 / 89	70
▨ PHASE 4	6 / 89 TO 9 / 89	100

storeys. The vertical load-bearing system comprises:

(1) 375mm ribbed slab spanning 6.4m or 8m onto main cross beams: The latter are typically 600mm wide by 1.2m deep, and span about 13m between the 600mm × 1.8m main columns. At second and third floor they increase in depth and cantilever to support the terraces, and at first floor they span onto other columns to carry the lowest terrace.

(2) The ends of the building cantilever about 3.6m from the end columns. The ribs span between main and facade beams. The latter in turn are supported on edge beams which run along the line of the building and cantilever past the end columns.

(3) The ground floor is a 150mm thick ground-bearing slab, on 1.8m pile caps and groups of 457mm diameter friction piles, founded in the CDG, and records indicate that they are typically 15m long, with about 700kN capacity.

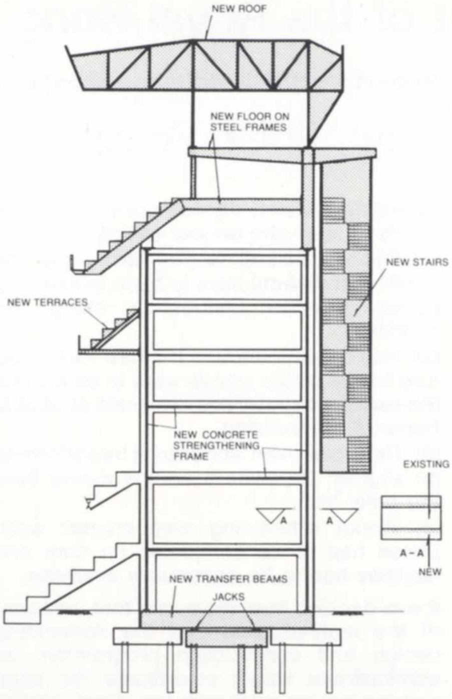
Design constraints

These were quite exacting, and raised the following structural problems:

(1) The height was increased by three storeys (about 40%), and the width by about 30%. This increased wind forces by 50% and 70% respectively at right angles and parallel to the stand.

(2) The additional floors increased vertical loads by about 50%. Some two-thirds of the increased load is carried by columns on the rear elevation because of the cantilevered rear stairs. All these new loads have to be transferred down from the top of the existing structure.

(3) The existing structure is somewhat 'brittle' in structural terms, e.g. if one main column settled, say, 15mm more than its immediate neighbours, cracking of spandrel beams might well result.



4. Structural system: principal elements.

(4) New foundations could not be placed outside the building line. Any within the building would have to be installed in low headroom.

New structural systems

The key point was that new foundations, placed quickly and in low headroom, were required to carry all the new loads and prevent damage to the existing structure. The new structure had to be lightweight, therefore, and especially so for the cantilevered rear stairs. In principle, all new loads, including wind, had to be carried by new strengthening structure to the new foundations, so the existing structure would actually be subjected to less load due to the removal of the original roof.

The principal elements of the new structural system (Fig. 4) consist of:

(1) New concrete floors acting compositely with steel beams to minimize floor weight, spanning onto steel frames and roof trusses to reduce weight and allow fast erection

(2) Lightweight steel hanging stairs cantilevering over the rear elevation and generating additional space in the building (Fig. 5)

(3) A reinforced concrete strengthening frame sandwiching the existing columns and beams to carry the new loads to foundations

(4) Transfer beams at ground level to take the new loads to the only possible new pile cap locations, between the existing pile caps

(5) 500mm diameter friction piles bored in temporary casings to minimize disturbance to the existing piles, providing a 'stiff' pile with low settlement characteristics. Specially modified rigs installed these within the limited 4.5m headroom

(6) A system of flatjacks transferring the new loads to the new foundations, minimizing any possible differential settlement.

Lateral stability was provided as follows:

(1) The roof cantilevers resist lateral loads via a raking prop-tie element at the rear of the truss from level 8 to the roof, whilst longitudinal loads are resisted by braced bays in the front and rear plantroom walls.

Building services

Ron Cookson
K.O. Yeung
Robert Cheung

Outline

A wide range of systems was utilized, incorporating some unique features needed to meet specific requirements. Services provisions were also relatively complex in terms of operational requirements, and because of the multiple phasing. The principal systems were:

(1) Air-conditioning and mechanical ventilation

(2) Hot and cold water supply

(3) Soil and waste drainage, and surface water drainage

(4) General lighting and power, emergency power, low voltage distribution

(5) Lifts and hoists

(6) Telecommunications

(7) Public address

(8) Building management and security

(9) Information systems for betting

(10) Fire detection and protection; lightning protection.

The establishment of a multi-disciplinary building engineering design team offered a number of benefits. Firstly, it helped early resolution of basic design planning issues, such as the provision of top-hung rear service ducts and co-ordination of all major plant inside the new steel roof structure. Secondly it led to the faster communication of design ideas and resolution of co-ordination problems. Thirdly, it meant that commissioning and handover of various services could be planned and sequenced effectively.

Services in the infield

Here, the service runs are neatly arranged in parallel under the roof, which was subject to height restrictions and thus affected the services design (Fig. 8).

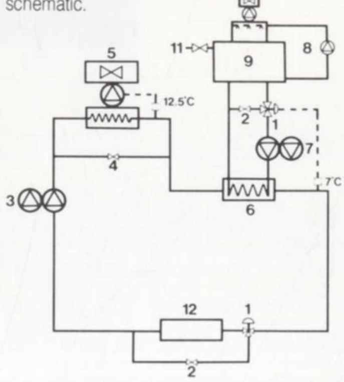
The unique air-conditioning demands of a racecourse once or twice a week on racedays, with intermittent periods for system re-charging, were dealt with by an ice thermal storage system (Fig. 9). This was a pilot study for the introduction of the technique to Hong Kong. It allowed cooling to the infield with the limited available power supply, whereas conventional cooling would have necessitated an uprated high voltage supply across the tracks.

Public and members' blocks

Main horizontal distribution was on the roof, with vertical distribution down the new rear ducts, serving subdivided service zones on each floor. The final services distribution to terminal points within occupied space was further restricted by the deep structural beams for the cantilevered terraces. The limited roof profile of the grandstand buildings made rationalization of the systems essential to achieve neat and well-thought-out plant layouts.

8. Service runs under roof.

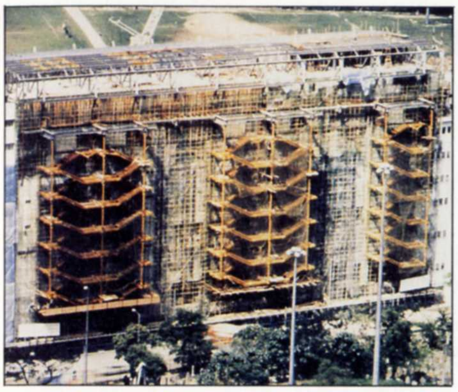
9. Ice chiller plant: schematic.



1. Three port control valves
2. Balancing valves
3. Chilled water pumps
4. By-pass isolating valve
5. Air-cooled water chiller
6. Heat exchanger
7. Ice-water pumps
8. Ice-water re-circulation pumps
9. Ice storage tank
10. Air-cooled packaged ice making machine
11. Water make-up
12. Cooling load

Sensibly cooled fresh air, to the USD's requirements, provides comfort cooling in the public betting halls, which are pressurized by the added fresh air against infiltration from the open sides. Sensible cooling was also introduced in the upgraded catering and kitchen areas.

The application of flush valves and concentrated demand for flushing during races necessitated reliable water storage with continuous inflow.

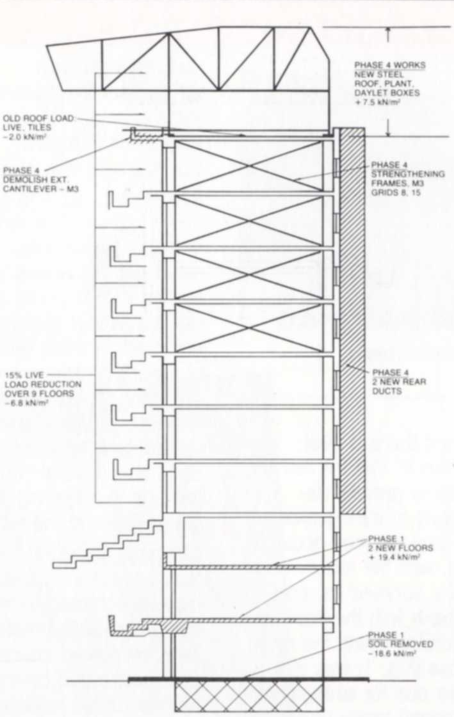


5. Lightweight steel hanging stairs.

6. Bracing between rear elevation columns.

(2) The new level 6 to 8 structure resists lateral loads by portal frame action and longitudinal loads by bracing in bays between rear elevation columns away from the rear stairs (Fig. 6).

(3) Between ground and level 6 the strengthening structure and existing frame together resist lateral loads and carry them down to the piles.



7. Use of steelwork on refurbishment.

Members' block M3

Two new mezzanine floors were added here in Phase 1. A new roof and replacement rooftop plant were to follow in Phase 4, as well as the two new service ducts. The major structural challenge was to carry the additional loads, and to assess, strengthen if necessary, and justify the existing structure for its new use.

New roof structure

The new lightweight roof consisted of steel trusses and floor beams spanning onto new columns directly over the existing reinforced column tops, providing a consistent roofline with the remainder of the refurbished grandstand (Fig. 7). To provide useful plantroom space a number of the frames were vierendeel trusses, lateral stability being provided by a combination of bracing and portal action.

Vertical load assessment

The principles of justification of the existing structure to carry the new loads were as follows:

(1) The additional load of the two new Phase 1 floors was approximately balanced by the reduction caused by excavating soil below ground slab and above pile cap levels.

(2) The proposed additional load of the new roof works and consideration of the actual weight of plant averaged over the roof plan area is about 4kN/m².

(3) In the original design no account was taken of possible live load reduction and it was proposed to consider a live load reduction of 15% for the building to justify the use of existing foundation. This reduces load at founding level by more than 4kN/m².

(4) Further use of live load reduction and new calculations on column capacities were used to justify individual columns at higher levels.

Wind load assessment

A 20% increase of wind load resulted from the 8m higher structure of the new roof, and so a new bracing wall was introduced at one end, matched by an existing reinforced concrete stair wall at the other. Because live loads had been reduced, the extra bracing had only to be carried down through four floors. Below that level, the existing columns could cope.

An underground well water storage tank was chosen as the solution, with sufficient water in-fill during intermittent off-peak periods to cope with the water demand and mode of operation.

New steel reinforcement in the concrete frame and foundations was utilized as the earth electrode for the lightning protection system in the refurbished P1 and P2 buildings. The profiled metal roof covering P2, P1, M1, M2, and M3 buildings was made an intrinsic termination of the lightning protection system, bonded via steel stanchions to the reinforcement.

Two new 4.5MVA sub-stations on the roof of P1 and M3 satisfied the increased electricity demand, replacing those on the ground floor and releasing space for betting-related activities.

The main services elements are as follows (Fig. 10):

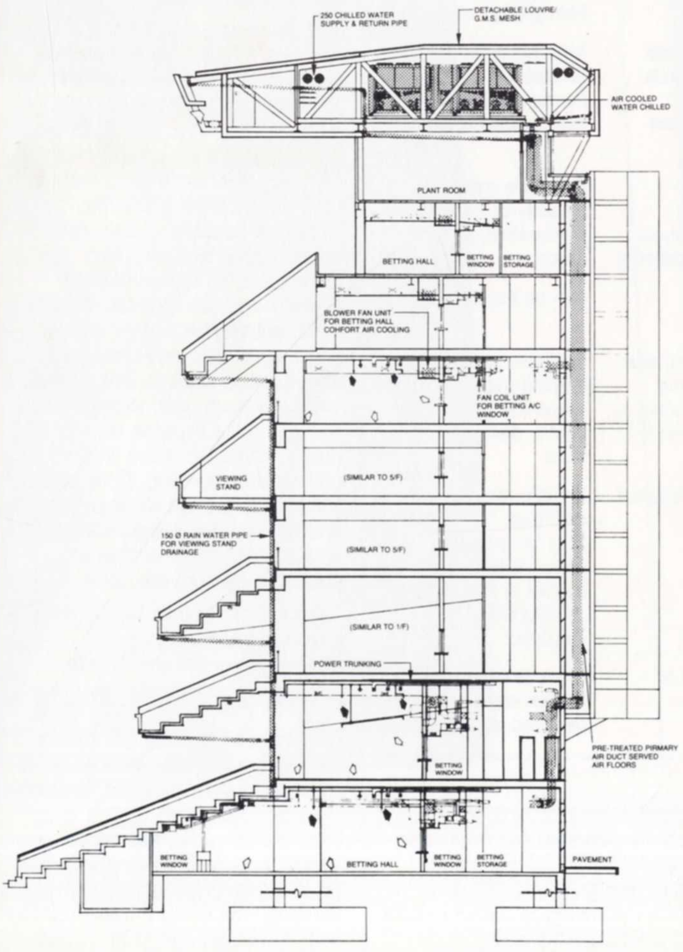
(1) Chilled water pipes running between structural columns

(2) Chillers contained in the structural roof shell

(3) Services corridor for risers to transfer from rear ducts to the plantrooms, and to provide the services shafts with proper means of access

(4) Final services distributions to terminal points within the occupied space between the deep structural beams

(5) Prefabricated structural openings for minor services distribution along the building.



10. Main services elements.

Credits

Client/Project manager:
Royal Hong Kong Jockey Club

Architect:
Robert Matthew,
Johnson-Marshall & Partners

Structural and services engineers:
Ove Arup & Partners

Quantity surveyor:
Levett & Bailey

Programme/Co-ordinator:
Trett Wardale Ltd.

Main contractors:
Hip Hing Construction Co. Ltd.
(Phase 1)

Shui On Construction Co. Ltd.
(Phases 2 & 3)

Crossing Interior Ltd.
(Phase 4)

Photos:
Ove Arup & Partners
Hong Kong Ltd.

DESIGN FOR HAZARD: EARTHQUAKE

Introduction

Earthquakes are one of the most challenging of the great forces of nature that engineers have to cope with. Striking without warning, they can cause within the space of a few minutes massive destruction and loss of life. During this century 1.4M people[1] are estimated to have lost their lives as a result of earthquakes and in the past five years alone, losses in excess of $1bn have been caused by single events in Chile, Mexico City, Armenia, San Francisco Bay (Fig. 1), Newcastle, Australia and the Philippines. The vast majority of this catastrophic toll was due not to the earthquakes themselves but the unsuitable buildings that collapsed because of inadequate design. This clearly places an immense responsibility on the structural engineer designing in earthquake country. However, a clear and in many ways comforting lesson emerges from the earthquakes listed above, all of which were studied by British teams involving Arup engineers[2-6]. Almost all the failures involved neglect of simple fundamental rules of earthquake engineering and so (with hindsight) were preventable. By contrast, modern well-engineered structures which observed these rules survived the recent great earthquakes and there is overwhelming evidence[7] that the technology now exists to prevent life-threatening failure in earthquakes, even if some damage may occur. San Francisco, with the money and time to prepare, survived its most recent earthquake with the fabric of society substantially intact; the most notable collapse (Fig. 1) was in a 1950s structure due for strengthening and (with hindsight) totally unsuitable for its location. By contrast, the similar-sized event in Armenia the previous year had struck an unprepared community with inadequately designed buildings. The death toll, at 25 000 people, was 400 times greater and the stricken communities will take many years to recover, even under favourable circumstances.

1. Failure of Cypress Viaduct, Oakland, 1989.

Table 1: Main differences between wind and earthquakes

		Wind	Earthquake effects
(1)	Source of loading	External force due to wind pressures	Applied movements from ground vibration
(2)	Type and duration of loading	Wind storm of several hours' duration; loads fluctuate, but predominantly in one direction	Transient cyclic loads of at most a few minutes' duration; loads change direction repeatedly
(3)	Predictability of loads	Usually good, by extrapolation from records or by analysis of site and wind patterns	Poor; little statistical certainty of magnitude of vibrations or their effects
(4)	Influence of local soil conditions on response	Unimportant	Can be important
(5)	Main factors affecting building response	External shape and size of building; dynamic properties unimportant except for very slender structures	Response governed by building dynamic properties: fundamental period, damping and mass
(6)	Normal design basis for maximum credible event	Elastic response required	Inelastic response permitted, but ductility must be provided; design is for a small fraction of the loads corresponding to elastic response
(7)	Design of non-structural elements	Loading confined to external cladding	Entire building contents shaken and must be designed appropriately

Wind and earthquake loading

Earthquake-resistant structures are often designed for a specified level of horizontal force resistance, in a similar way to wind design. There are important differences between wind and earthquake loading, however, as listed in Table 1.

Thus, the dynamic nature of the response to earthquakes, the potentially degrading effect of large amplitude cyclical loading on building and foundation materials and the uncertainty in design motions are the fundamental points; understanding these forms the key to successful earthquake-resistant design.

Seismic design of superstructures

Aims of structural design against earthquakes

The first objective of the designer after a rare, extreme event is to ensure safety. The structure should therefore be designed to be in a safe condition after such an event, so that its occupants can safely leave it even if some damage has occurred. In more likely earthquakes of lower intensity, a second objective of limiting the economic consequences should also apply, and the designer should seek to restrict both structural and non-structural damage. Some pointers to achieving these two objectives form the rest of this article.

Choice of structural material and form

Successful earthquake resistance may be achieved in most of the common building materials, including steel, reinforced concrete, precast and prestressed concrete, timber and reinforced masonry. The choice between steel and concrete will depend on many factors, not just the earthquake aspects, though it is probably true that for very high-rise buildings, the favourable strength-to-weight ratio of steel will usually outweigh the stiffness and other advantages of concrete. Unreinforced masonry is a brittle material, unsuitable for earthquake country, but reinforced masonry has been successfully used for low rise structures. Well-maintained timber also has a good record of resistance in low-rise buildings.

The choice of a flexible or stiff structure will also depend on a number of factors. Flexible unbraced structures tend to have long natural periods which often take them out of resonance with the ground motions. Offsetting this, the large deflections caused by their flexibility may result in distress to cladding and other non-structural elements. Also, concrete unbraced frames depend crucially on quite complex reinforcement arrangements which require good supervision and competent steel fixers to achieve. Braced steel structures have good strength and stiffness at the expense of reduced ductility, because failure is often governed by buckling. Concrete shear walls provide stiffness, strength and (with proper design) considerable ductility, and are often a good choice for medium-rise construction.

Two developments in recent years have sought to combine the advantages of stiff and flexible structures. The 'eccentrically braced frame' or EBF structure (Fig. 2) has steel braces providing stiffness for moderate earthquake motions but a sacrificial ductile shear link between the braces designed to yield in an intense earthquake, absorbing seismic energy and acting as a fuse which prevents the braces from buckling. The Century Tower building (Fig. 3), designed in Arups' London office and currently under construction in Tokyo, adopts this principle.

A more radical concept is that of base isolation (Fig. 4), where a stiff structure is mounted on bearings designed to detune it from the underlying earthquake motions. Some 80 building and bridge structures have been constructed to date which adopt this principle; the Museum of New Zealand, currently being designed by Arups' Auckland office in conjunction with the Holmes Consulting Group, will be protected by this system.

Structural layout

The experience of past earthquakes has confirmed the commonsense notion that buildings that are well tied together and have continuous lateral load paths to the foundation perform far better than buildings without such features. A less obvious finding is that buildings with significant degrees of horizontal and vertical irregularity are found to perform 5 to 10 times worse than regular buildings[8]. A classic example of vertical irregularity is the open or soft ground storey (Fig. 5), which causes a concentration of damage at that level. This has perhaps been responsible for more collapses than any other single fault. An example of horizontal irregularity is the eccentric shear core (Fig. 6), which allows damaging torsional motions to build up.

A seismically regular building need not imply uninteresting architecture. The Century Tower has a high degree of symmetry while achieving striking effects. The Children's Hospital at Stanford, emanating from the Los Angeles office, has a far from dull exterior, while eliminating torsional effects by carefully balancing mass and stiffness.

Ductile and brittle responses

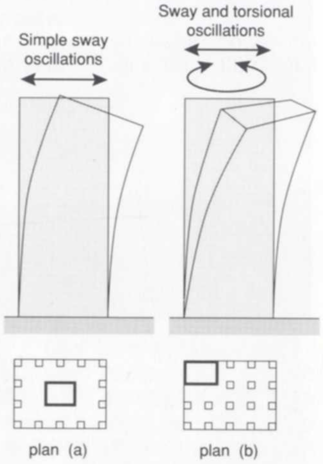
A further vital ingredient is needed to ensure that there is adequate reserve to prevent collapse in an extreme and possibly greater than expected earthquake. This is the property known as ductility, defined as the ability to undergo repeated yielding cycles without brittle failure. The commonly adopted strategy among earthquake engineers is to accept that in an extreme event, the structure will yield and be damaged, possibly to the extent that it is irreparable. The ductility, however, ensures that life-threatening collapse does not occur and the earthquake is ridden out not by brute strength but supple, ductile yielding. The history of failures in earthquakes is primarily one of the collapse of non-ductile structures.

How can this be achieved? Clearly, brittle materials must be avoided; some steels, particularly if welded, are brittle and must not be used. For structures with properly specified steel and concrete properties, the solution is to ensure that yield occurs first in ductile failure modes, such as tensile yielding of steel tension members or bending of under-reinforced concrete beams. Brittle modes such as shear failure in concrete, failure of steel connections or

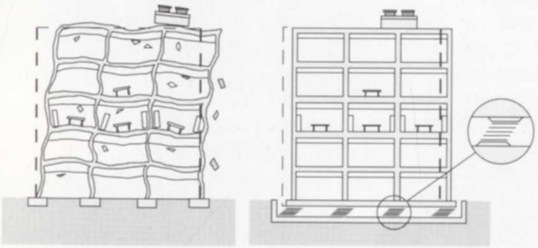
2. Sway mechanism of EBF (eccentrically braced frame) structure.

3. Century Tower, Tokyo.

5. 'Soft storey' building which was damaged in the 1976 Friuli earthquake, and collapsed in an aftershock.



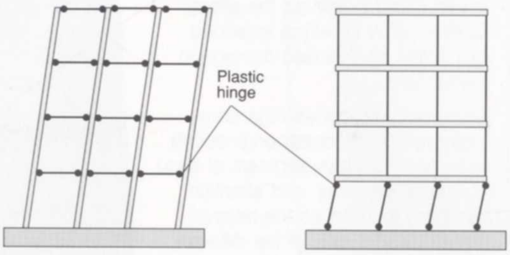
6. a) Regular and b) irregular plan structural layouts.



Conventional structure

Base isolated structure

4. Principle of base isolation.



Strong column / weak beam
Good ductility

Weak beam / strong column
Poor ductility

7. Favourable and unfavourable arrangements of relative member strengths.

buckling of struts must be avoided by provision of appropriate overstrength.

A successful ductile structure will therefore be one in which the ductile yielding modes form weak links or fuses which limit the build-up of forces in brittle failure modes. Achieving this is partly a matter of detailed design, but the overall layout of the structure can also have a major influence, as has already been described for EBF structures. As another example, a strong column/weak beam unbraced frame structure (Fig. 7) has good ductility, because yielding is by bending of beams and is well spread through the structure, lowering the demand at each yield point. Such a structure will prevent the soft storey formation referred to previously (Fig. 5); it will result in much larger column sizes than would be required for gravity considerations alone, but the evidence from past earthquakes strongly supports the danger of neglecting such provision (Fig. 8).

Geotechnical aspects of seismic design

The foundations and underlying soils must of course not be neglected in any structural design and this is especially true for earthquake effects, which are unusual in that the soil both supports *and* loads the structure.

Foundation design

Life-threatening collapse of structures due to foundation failure in earthquakes is comparatively rare, except in the cases discussed below where soil liquefaction occurs. Nevertheless, such failures (Fig. 9) can occur and must be considered in design.

The foundation should be designed to transmit the static and dynamic loads applied to the soil without inducing excessive movement and must be given adequate strength and ductility to behave in a ductile manner if an overstress of the foundation structure can occur. Piles, particularly those with large diameter, need special consideration, since they may be subjected to large additional lateral forces from the soil mass attempting to move past the soil group. If these aspects are borne in mind, a seismic foundation design can follow essentially similar lines to design for normal static loads.

Soil liquefaction

Under the cyclic effect of earthquake motions, loose saturated sands can lose their strength in a process known as liquefaction. This has led to dramatic foundation failure in buildings and bridges in a large number of earthquakes, most recently the 1990 Philippines event (Fig. 10).

The first step is to consider whether the foundation soils are potentially liquefiable, a process which is still something of a black art but which can now be done with a measure of confidence[9]. Having established that there may be a problem, the solution is either to fight it in some way or flee to another site where liquefaction is not expected — an option which, though often unpalatable, may deserve serious consideration. The 'fight' options can be divided into two. As a first option, measures can be taken to reduce the soil's tendency to liquefy, for example by dynamic compaction or grouting. Alternatively, the foundations can be designed to cope with the liquefaction, by reducing effective stresses or by founding onto stable layers. Neither option is straightforward and the soil improvement measures are likely to require some trial and error to be successful.

Slope stability

Unstable slopes frequently move in earthquakes and an obvious rule is to avoid building on them in earthquake country. The point was made by the great Irish seismologist Robert Mallet in 1865[10] and may seem so self-evident as to be not worth making. Nevertheless, neglect of this rule has caused disaster on many occasions; the advice of the geotechnical engineer will be on the level of slope stability required, commensurate with the seismicity of the site. Even slopes as shallow as 5° may become unstable if liquefaction is a possibility[11].

Site effects

Often the most important specialist role of the geotechnical engineer in seismic design is to pronounce on the possibility of site effects, in which soft layers of soil overlying rock can amplify the underlying seismic motions. The most dramatic recent example occurred in Mexico City in 1985, where the lake bed soils transformed an essentially harmless motion into a high amplitude single frequency oscillation which was particularly damaging to buildings in the 12 to 20-storey range. There is ample evidence from other earthquakes that similar, if often less extreme, amplification frequently takes place.

Geotechnical engineers are now confident that they can predict such effects with reasonable accuracy, given good information on the soil succession down to bedrock[3]. They can provide the structural engineer with information on the degree of amplification to expect and also on the range of frequencies at which this amplification will occur. The structural engineer will then be well advised to ensure that the

▶

8. Column failures in the 1985 Mexican earthquake.

9. Foundation failure, Mexico City, 1985.

10. Liquefaction-induced bridge failure, Philippines 1990.

▸ Earthquake (concluded)

proposed structure has a natural frequency well away from this site period, to avoid the resonance effects that have brought down so many buildings in Mexico City and elsewhere.

The way forward

Earthquake engineering is a rapidly developing field; new and exciting advances in seismology, analysis and design are being made all the time. Arups keep in close touch with the latest research; for example, we are involved in designing high technology structures which respond in real time to earthquake motions by means of computer-controlled masses, and are carrying out a major programme of research with the University of Bristol on their new earthquake simulator. There is no doubt that these and many other developments will help make the world a safer place in this, the UN's International Decade for Natural Disaster Reduction.[12]

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DESIGN FOR HAZARD: FLOOD

3. Jaywick Sands, Clacton.

Introduction

The increased risk of flooding has been the subject of many forums. Serious flooding attacking Britain's coastline occurred notably in 1953, 1978 and most recently in the winter 1989/90 Towyn disaster.

Significant areas of valuable agricultural land, urban conurbations and industrial complexes have been protected against the highest storm surges experienced since the catastrophic tidal flooding of 1953 in East Anglia which caused the deaths of 300 inhabitants and caused considerable damage to sea defences and agricultural land. As well as many areas of the country heavily developed by residential, commercial and industrial zones, 720 000 ha Grades I and III land lie below 5m, including some of the best agricultural land. This is indicated on Fig. 1. This includes 57% of all Grade I agricultural land (Ministry of Agriculture, Fisheries and Food classification). The most extensive coastal lowland in the United Kingdom is the Fenland of East Anglia, and most of this is Grade I agricultural land. It is already well below +5m OD and therefore at risk; areas immediately east of the A1 are −2m OD and about 45km from the present coast. Sea levels experienced in 1953 were equalled or exceeded in the late 1970s, but, apart from the recent Towyn disaster, without the effects suffered in 1953, which extended well inland and caused damage to inland defences.

Arups have recognized the paramount need for coastal engineering expertise in the development of flood alleviation schemes, and attention has been focused on the relative merits and demerits of the different options available for such work. Agencies which fund such schemes are increasingly expressing concern on the investment of limited resources on flood defence works.

Arups have proposed innovative schemes which encompass both a full appraisal of potential flood damage and the overall benefits to society; the assessment of the impact of such schemes upon the environment must be given due priority in evaluating the overall worthiness.

1. Areas below 5m Ordnance Datum already in need of protection from storm surges and sea level rise.

Coastal defences in England and Wales are governed by two main Acts of Parliament, the Land Drainage Act 1976 and the Coast Protection Act 1949. In general the former is applied to low areas liable to flooding and the defence works are referred to as sea defences, whereas the Coast Protection Act relates to protection against erosion. MAFF is responsible for administering the Acts in England, and the Secretary of State for Wales is responsible in Wales. In Scotland, the Secretary of State for Scotland has similar responsibility administering the Land Drainage (Scotland) Act 1958, the Flood Prevention (Scotland) Act 1961 and the Coast Protection Act 1949. In Northern Ireland, the Secretary of State for Northern Ireland is responsible for administering the Drainage Order 1973.

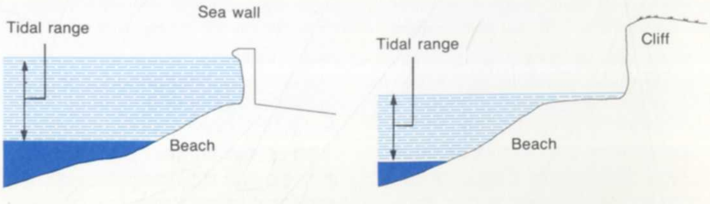
Responsibilities for the actual sea defences in the coastal zone fall to the various Regions of the National Rivers Authority (NRA), which have taken over the sea defence role from the former water authorities. Fig. 2 indicates the approximate definition of flood and sea defence.

Coastal defences, defined as coastal protection under the Coast Protection Act, are the responsibility of local authorities such as district councils. There are 88 of these Coast Protection Authorities in England. If one adds the equivalent authorities in Wales, Scotland and Northern Ireland, together with the established ports, then the total number of authorities concerned with the coast is about 240.

The United Kingdom defences were not built to modern standards and their repair and replacement now pose serious problems. Even structures built following the 1953 flood are in some cases nearing the end of their design life.

It is difficult to state with accuracy the current capital value of the existing coastal defences, but it is probably in excess of £4000M. The estimated current expenditure on replacement, reconstruction or repair in order to maintain the present level of protection is of the order of £150M per year. Table 1 gives an indication of the scale of the cost of rising oceanic levels on sea defences.

Winds, waves, tides, surges and sea and land level changes do not recognize administrative boundaries. The proliferation of separate authorities responsible for coastal defences has in the past resulted in the implementation of local schemes which did not take account of their potential effect on adjacent areas. Consequently the protection of one area has resulted in erosion elsewhere. This tendency is still present, especially when works are carried out as a matter of urgency, which is frequently the case.



2. Flood defence (left) and sea defence (right).

The greenhouse effect

Globally, sea levels have been increasing by 0.1m-0.15m per century since 1870 and it is, therefore, necessary to anticipate the effects which a rise in sea level would produce.

The Report of the Intergovernmental Panel on Climate Change was discussed at the Second World Climatic Conference in November 1990 and it is expected that firm recommendations will ensue from this meeting.

Not only are many of the defences built after 1953 reaching the end of their useful life, needing rebuilding or major refurbishing, but possible rises in sea levels of 0.2m by the year 2030 and 0.65m by 2100 have to be faced — an average of 60mm per decade, within a range of 30-100mm. Moreover, the design of many structures has aggravated beach erosion, and new designs have had to be produced to combat the damaging effects. If there is a change in climate it could alter existing beach-building processes, and a good deal more research and monitoring are needed. Additionally, protection to cliffs precludes the natural supply of beach-feed materials, with the consequence of further beach lowering.

On the assumption that a significant rise in sea level will take place, the two major effects depend on the influence of climatic change and on the frequency and severity of storms, and this is more difficult to assess. Moreover, increased water levels and more severe wave attack will result in overtopping and damage to coast defences. The significance of these changed environmental conditions for existing and future sea defences will thus vary from place to place.

Structures designed for existing conditions will require replacement or development as overtopping becomes increasingly more probable. Groynes will need to be raised and extended landwards together with revetments. Dunes will likewise come under attack. As at present, the choice of a design probability will have to be made in the light of the cost of the resulting loss or damage in each particular locality.

The greatest impact of such a rise in sea level would be on soft coasts protected by sea walls. As the sea rises, erosive processes would become dominant and there would be considerable losses, especially of fine sediments. The slope of the shore would become steeper and each zone narrower. The sea wall would have to withstand increased erosion following the loss of the salt marshes, mud flats and beaches to seaward.

Failure to provide adequate coastal defences will mean loss of life, property and land — not only in areas of low grade marginal land but also those of high environmental value such as the wetlands of the Severn and Thames Estuaries and the peripheral land around the Wash. Areas like the Fens will also be at risk from rising salt levels and destruction of the freshwater habitat.

Table 1

Rise in sea level (m)	Range of estimated cost £M	Area affected (ha)	Commentary
0.1	0 – 200	6400	Dependent on reduction of permitted freeboard
0.3	400 – 900	19 200	
0.5	800 – 2000	42 000	

Possible action

There will be areas where protection is neither vital nor economically justified. For the purposes of Grant Aid (i.e. central funding for coastal protection) MAFF cannot justify protecting ordinary agricultural land due to its low value, so a strategy for zoning existing land on the assumption that it may have to be abandoned should be adopted. Various other options will have to be considered, including raising the existing sea walls, building new walls further inland, and building storm-surge barriers.

However, uncertainties in the possible future rise in sea level focus attention on the need to adopt a flexible approach at the present time by making provision in current designs for increasing the height of defences over the life of the structures. Currently, a relative sea level rise of 0.3m per century is taken into account in designing sea defences. This is about twice the present trend in sea level rise.

The regional coastal groups of local authorities are making efforts to collect, collate and disseminate local information, and collaborate in the study of problems of mutual interest, which will provide the basis for an urgent, nationally-organized coast defence management study so that local schemes can be based on regional strategic plans. This will enable the best disposition of the extra funds required to take account of the anticipated effects of sea level rise and climate change on existing defences, and on plans for defence in depth or abandonment of some land areas. Worst case scenarios suggest that the annual cost of protecting the coast could rise by a factor of two or threefold, and would have to be maintained for several decades.

It is apparent that there is need for a national plan for the continuing collection of wave data in areas sensitive to flooding or erosion.

Planning authorities should consider the designation of 'set back' lines to control development in vulnerable coastal areas.

The intangible benefits of amenity, recreation and the preservation of the environment must be given a place in cost benefit studies relating to coastal defence.

The cost of protection is not cheap. Sea wall construction currently costs £5M/km. Anglia region alone has identified the need to spend £131M in the next 10 years. Of the NRA current annual expenditure on capital works of £50M, a significant proportion is spent on tide defences. The projected rise in sea level could result in the need to spend £5-£8bn in total.

Sea and tidal defences capital schemes are funded partly by MAFF, and partly through levies on councils. This is a potential constraint on NRA capital programmes. All works are subjected to benefit/cost analysis, and some difficulty is being experienced in justifying protection schemes in the face of the down-turn in agricultural output values, the need to find substitute benefit, or political decisions to prevent loss of land.

Funding of defence structures is a heavy burden on local residents, and there may be a need for recognition of this as a national problem and hence the provision of central funding to ease disparities, especially between regions of the NRA.

The following facts concerning expenditure on research should be noted:

(1) Current expenditure on basic and applied research in coastal engineering is roughly £4M per year.

(2) Current value of engineering works and activity in this area by the United Kingdom is about £450M per year (excluding ancillary works).

(3) Current expenditure on specific investigation/commissioned studies is also about £4M per year.

(4) Current spending on basic/applied research is therefore less than one penny in the £.

Conclusion

Land below +5m OD already at risk from storm surges and high tides should not be developed for industrial, residential or strategic purposes. All development plans must consider these risks and ensure that the risk is neither extended nor intensified by permitted land use changes.

The key issues for flood defence work are:

(a) Is there global warming and what is the real impact on coastal defences? How fast will the effects of such warming be upon us?

(b) Understanding the natural processes along both coastline and estuaries.

(c) Developing and using solutions which are in accordance with natural processes and thus attempting to minimize the impact on the environment and our heritage.

(d) Establish the investment needs of the necessary coastal defences.

Attempts will be made to avert the impact of major flood events, but the flood hazard will never be removed entirely.

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