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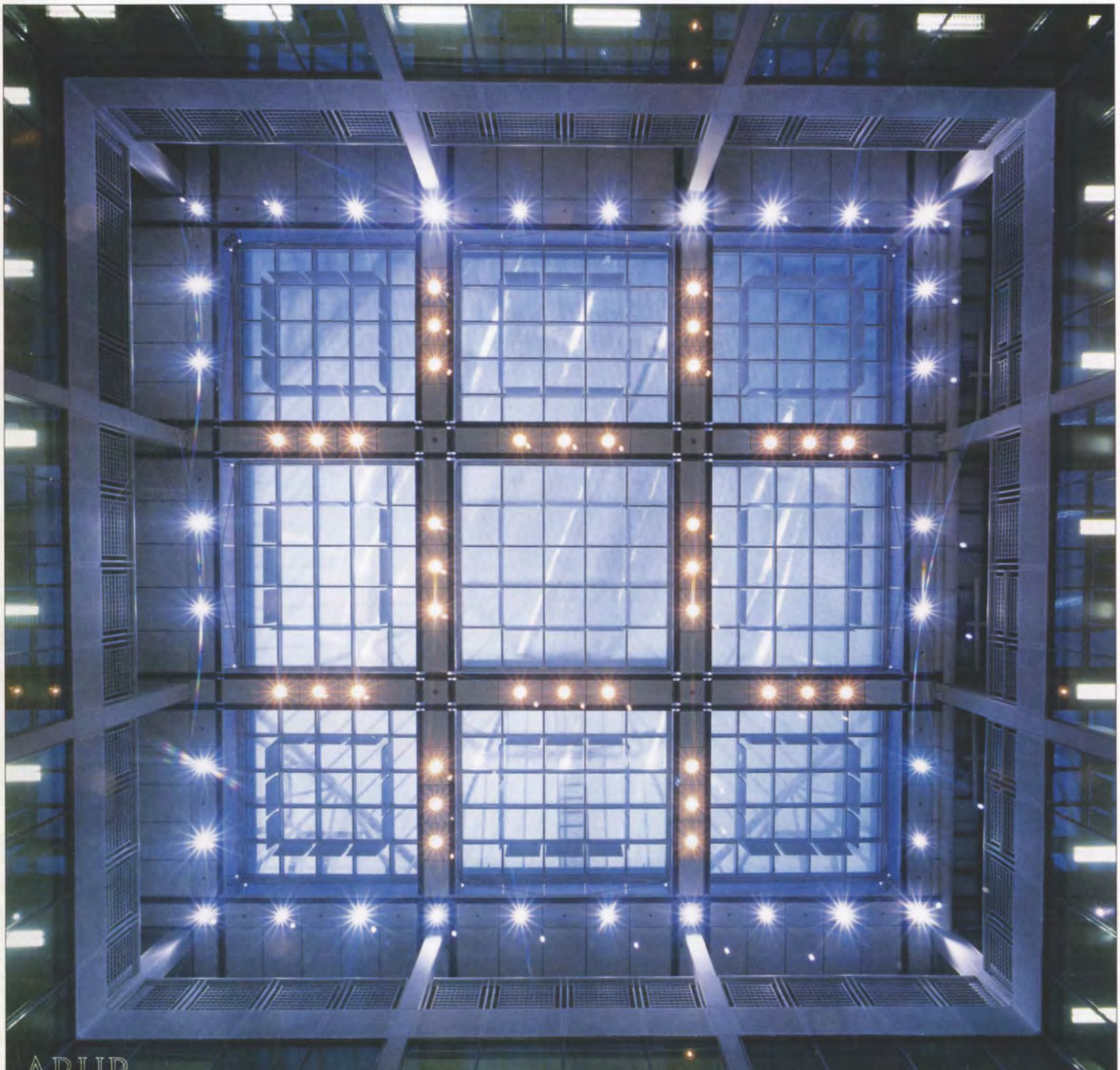

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Ove Arup Partnership Ltd.
13 Fitzroy Street
London W1P 6BQ
England

Tel: +44 (0) 20 7636 1531
Fax: +44 (0) 20 7580 3924
website: www.arup.com
e-mail: corporate@arup.com

Editor:
David J Brown

Art Editor:
Desmond Wyeth FCSD

Deputy Editor:
Karen Svensson

Editorial:
Tel: +44 (0) 20 7465 3828
Fax: +44 (0) 20 7465 3675
e-mail: david-j.brown@arup.com

Front cover:
Atrium canopy at Warburg Dillon Read, 1 Finsbury Avenue, London (pp15-19)
(Photo: Nathan Willock)

Back cover:
Sual Power Station, The Philippines (pp23-29)
(Photo: Stevenson Kinder & Scott)


Brian Marriott

Arup supplied full engineer / architect services for two car factories in Gliwice, Poland, and Rayong, Thailand. Though they had virtually the same size, purpose, and layout, thus benefiting from a unified design approach by a single team, the widely differing conditions in Poland and Thailand created many challenges for the designers in finding appropriate local architectural and engineering solutions. The demands of tight deadlines, changing requirements, and multilocational operations tested the team to the full.


courtesy OAP Zimbabwe

On a very short timescale, Ove Arup & Partners Zimbabwe produced an Environmental Impact Assessment for the proposed construction of an opencast platinum mine near Ngezi Recreational Park. The EIA studied human resources and socio-economic aspects, and the impact on the site environment including vegetation, wildlife, and archaeological and cultural features. Arup's report was accepted, including many mitigation and control measures, and construction of the mine proceeded.


Peter Mackinven

The Ambulatory Care and Diagnostic Centre in north-west London is a new departure in health care for Britain's National Health Service. Arup worked closely with the client and architect to provide design solutions appropriate for the needs of separating elective care and emergency care, of providing flexibility and high quality internal environments, and of funding by Private Finance Initiative (PFI).


Nathan Willock

1 Finsbury Avenue was originally designed by Arup Associates in the early 1980s. Over 10 years later Arup was asked to provide a new environment for 1200 dealers within the existing space, and upgrade the building's IT and services infrastructure. A new floor was inserted into the full-height atrium, creating a new three-storey entrance space beneath and the dealer floor above. The former has a state-of-the-art flexible lighting environment, whilst the latter benefits from controlled natural and artificial light.


Gollings

Ove Arup & Partners Australia engineered this new steel footbridge across the Yarra River, linking Melbourne's Exhibition Centre and Convention Centre. The engineering challenges included the design of its full-length raking glass wall, the exposed interfaces between this and the steel structure, and the unobtrusive pier shrouds to protect the bridge against impact forces. Arup also designed the spectacular glass loggia enclosing the entrance area of the Convention Centre.


Stevenson Kinder & Scott

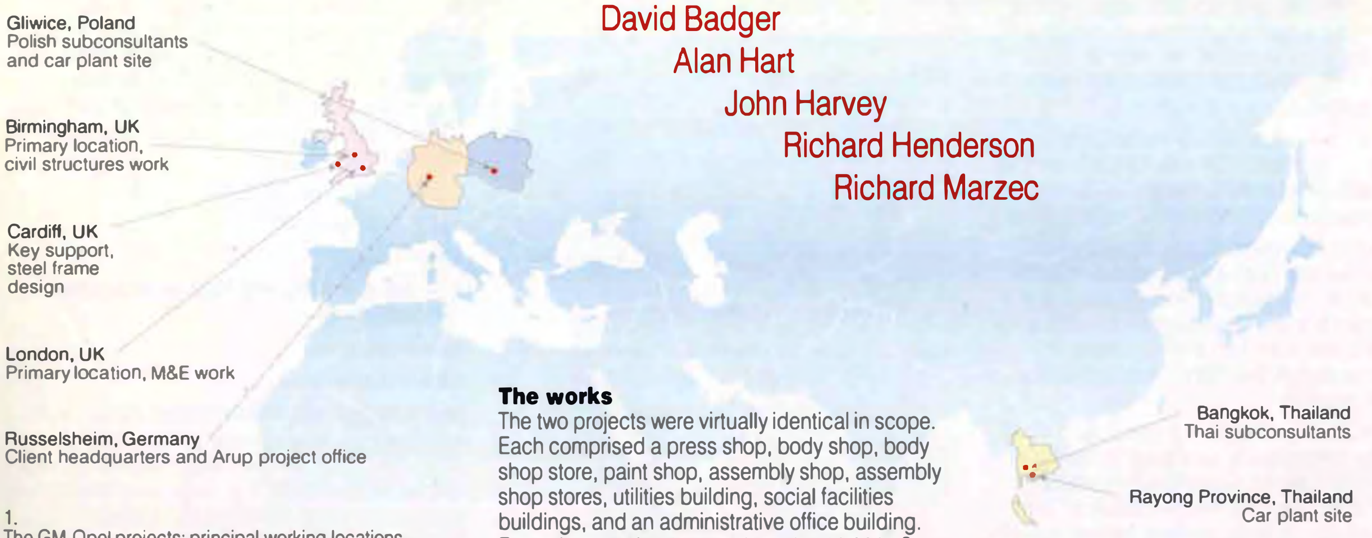
Sual Power Station is the largest and most efficient coal-fired facility in The Philippines. Following Arup's increasingly extensive design involvement with other South East Asian power stations, Arup Energy undertook the full civil, structural, architectural, geotechnical, and maritime engineering design, as well as further roles including aspects of contract procurement and project management, additional design packages, and a technical and commercial assessment of the cooling water system construction and operation.


Arup

In response to a worldwide increase in planning and constructing new railways, Arup's Advanced Technology Group has developed and validated a new methodology to predict structure-borne noise radiated from elevated railway structures. This article provides some background to railway noise and vibration issues, describes the CAE (computer-aided engineering) analysis method, and demonstrates the accuracy of CAE compared with measurements from an operating viaduct.

The Poland and Thailand GM-Opel projects

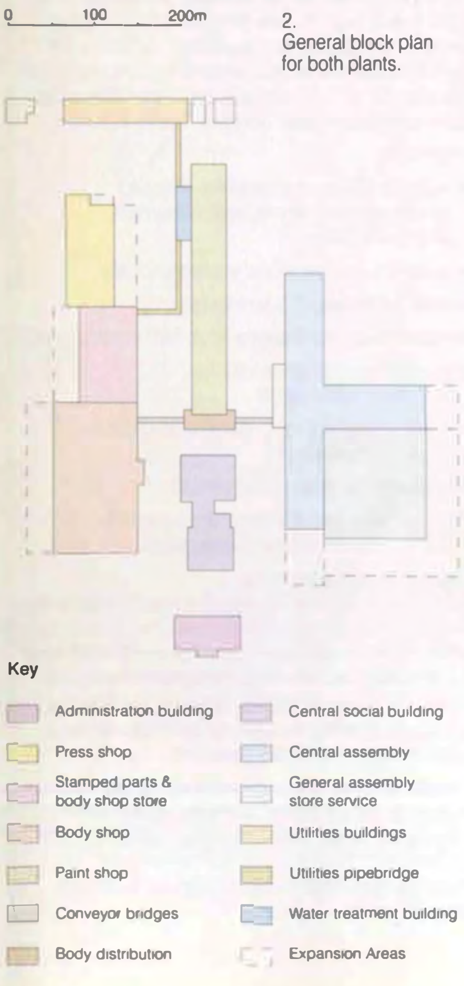
David Badger
Alan Hart
John Harvey
Richard Henderson
Richard Marzec



1.
The GM-Opel projects: principal working locations.

Project set up

In February 1996 Arup received an invitation from GM-Opel in Russelsheim, Germany, to bid for the provision of full architect / engineer services to three new greenfield manufacturing plants in Poland, Thailand, and China. Each was to be broadly similar in scope and size, so it was felt that there must be advantage in running their design and procurement concurrently with the same team. During the consultant selection process it was decided that the China project in Shanghai should be progressed independently, so the enquiry reduced to the Poland (Gliwice, Silesia) and Thailand (Eastern Seaboard Estate, Rayong) plants only (Fig 1). Over the following four months Arup reached agreement on its scope of services, proposed method of working and commercial arrangements, and was instructed to commence operations on 24 June 1996.



2.
General block plan for both plants.

The works

The two projects were virtually identical in scope. Each comprised a press shop, body shop, body shop store, paint shop, assembly shop, assembly shop stores, utilities building, social facilities buildings, and an administrative office building. Each site contained approximately 120 000m² of built floor area. Arup's responsibilities in both included all but the paint shops; these were procured through a separate 'turnkey' package.

The Arup brief

The firm's scope of services comprised responsibility for all site preparation and external works (ground shaping, drainage, hard and soft landscaping, utilities distribution); all building design (architecture, structural, mechanical, electrical, and public health engineering); all process utilities design; and assistance to GM-Opel with certain aspects of the process design (conveyors, communications systems).

Designs were to be executed through all stages to achieve client 'sign off', a comprehensive set of tender documents, working drawings, and all technical submission material for local permitting processes, which the firm was to manage. During the construction phases Arup was to supervise the contractors' technical input, provide technical support in relation to changes and other issues arising, and maintain a site team to supervise quality standards for the works the firm designed. Throughout, Arup was to be responsible for cost management of its designed work (pre- and post-design cost estimates; evaluation of constructed works and variations; final accounts), and the time management of the design processes - taking instructions from and reporting to the client project team in the GM-Opel International Technical Design Centre (ITDC) in Russelsheim, Germany.

The conditions of engagement were based on the German HOAI document, although in practice the logical progression through the design, procurement, and construction processes laid down in this document had to be compromised to achieve the concentrated timescales required. The completion dates laid down at the outset were start of vehicle production in Poland on 1 September 1998, and in Thailand on 31 January 1999. This gave periods for all design, construction, equipping, and commissioning, of 26 months (Poland) and 31 months (Thailand).

Organisation and management

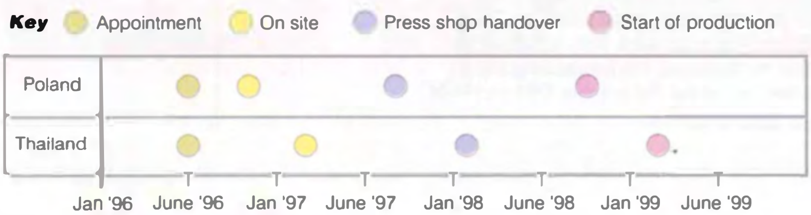
The size, speed, and multi-locational character of the job necessitated a clear approach to organisation and management, and key organisational principles were established at the outset and maintained throughout the project. It was run as a single entity and not split up into constituent parts, although clearly individuals within the team had primary responsibilities relating to specific parts. This had the advantage of maximising the benefits of synergy between the two locations and allowed key staff to support each other as needed without operating constraints.

A primary leadership team was appointed at the outset and these responsibilities were maintained throughout the project:

- *Project Director* (PD), with overall responsibility to the client and the Partnership for the execution of the project
- *Project Manager* (PM) with overall responsibility to the PD for the day-to-day management of the project as a whole
- *Thailand Project Manager* (TPM) with responsibility for implementing activities in Thailand
- *Poland Project Manager* (PPM) with the same responsibility for activities in that country.

Architectural sub-consultants were appointed separately for each site to reflect their individual suitability for, knowledge of, and experience in each location. In both cases a lead partner was nominated to take overall responsibility for his practice's work. During the project a third architectural practice was engaged with specific responsibility for the administration building in Thailand.

3 below:
Activity milestones.



In both countries, local sub-consultants were appointed early to advise on local construction practices, materials, and regulatory requirements, and at the later stages to undertake some of the detailed design, preparation, and submission of permitting information, and provision of support supervisory staff during construction.

Both sub-consultants were fully multidisciplinary (architectural, structural, civil, mechanical, electrical, public health) to promote an integrated design approach and to reduce the contractual interfaces.

Arup Discipline Leaders (structural, mechanical, electrical, civil, and cost) were appointed to lead their respective teams, again working across the whole project to maximise synergies. The discipline teams were resourced from many locations to reflect the expertise, experience, and availability of the staff required.

For the initial design stages (4-6 months) the focus for Arup's activities was a 'core team' located in a purpose-established project office in Russelsheim. This team comprised the PM, the PPM and TPM, the architectural practices' partners, representatives of each local sub-consultant practice, and a support team of technical and administrative staff, all predominantly resident. It team was supplemented by the PD and all the Discipline Leaders who visited Russelsheim regularly.

This arrangement allowed Arup to establish and maintain a continuous management relationship with the client at ITDC, and a technical relationship with each of the technical leaders at GM-Opel ITDC through the architectural and discipline leaders, as well as involving key members of the implementation teams in this initial 'job shaping' process.

The Discipline Leaders were able to maintain personal contact with both the ITDC team in Germany and their staff in UK to the benefit of both (and at the sacrifice of much travelling!)

During this first phase the enabling 'in-country' activities (ground condition surveys, topographical surveys, permitting requirements, tender lists, etc) were managed by the PPM and TPM, working in conjunction with their local sub-consultant representatives. Early working relationships were formed to the benefit of the handover to Phase 2 activities. This was all the work associated with detailed design and the construction and equipping stages, culminating in a 'raw' working facility. Arup's efforts at this time were focused in each country, led by the country PMs who were now established there. Initially the primary effort was within the sub-consultants' offices preparing the detailed technical documents, whilst Arup established embryonic site teams to supervise early enabling works in each location. Technical support through the Discipline Leaders and home-based resource continued, and the Russelsheim office continued to maintain communication lines with GM-Opel ITDC, albeit with an appropriately reduced staff.

As design works were completed and site activities increased, the Arup teams were more substantially established on site as were the client's representative teams from both GM-Opel ITDC and the 'in country' manufacturing organisations (Opel Polska and GM Thailand respectively) who were to take over the completed facilities. The final Phase comprised snagging of technical work, preparation and handover of finalising documentation, and completion of commercial agreements, and took place after the Arup site teams were substantially disbanded. Leadership at this time reverted to a central activity under the PM with the TPM and PPM providing a supporting role.

4. Phase 1 arrangements.

5. Phase 2 arrangements.

6. Phase 3 arrangements.

Procurement strategy

This had to respect both the demands of speed and the client's purchasing policies. To some extent there was a clash of interests, with the first requiring overlap between design and award, and the second requiring certainty of award basis as a condition of contract. This problem was addressed by subdividing the overall works into 'packages' representing:

- preliminary enabling works
- early foundation works
- steel frame
- remaining building and mechanical services (main package)
- electrical works
- finalisation works.

Each package was tendered in two stages, with the initial enquiry based on the best information available at the time. The second stage comprised a re-tender by a shortlist of companies determined from the first stage against more detailed requirements prepared in parallel.

Design

Overall considerations

In developing the design, Arup's over-riding concern was to meet the very demanding programme. The timescale for start of production - set before the firm's appointment - demanded world-class design and construction performance; to achieve start of production the manufacturing teams in GM-Opel needed five months for equipment try-out and staff training, thus limiting the time for design, construction, and equipment installation. The time targets for design were met successfully, despite some fairly major changes in the brief including building level changes in Poland caused by flooding concerns and a change of site (by 80km) for Thailand, both after the initial earthworks and drainage designs were prepared.

The overall site layouts and the disposition of the main production buildings were developed by GM-Opel ITDC before Arup's appointment; these layouts reflected the production requirements for space and product flow but did not include non-production spaces and buildings. Although the two layouts were similar, several factors had to be allowed for which created significant differences between the two final designs. These included:

- climate
- social facilities requirements affected by operative numbers, shift patterns, and break times
- materials and methods available locally
- local permitting requirements.

In developing the designs Arup had several goals:

- to minimise roof penetrations to reduce weak points
- to eliminate internal gutters or downpipes to assist construction
- to design for speedy construction
- to provide a good internal environment with minimum mechanical services.

Design for construction

From the outset one design aim was to enable easy construction, to reduce both cost and construction time. All the production buildings are of steel truss construction with as much repetition of sections and detailing as possible. Similarly, the finishes and services detailing throughout each project were kept the same wherever possible.

The roofs for all buildings were designed with slopes to the perimeter with only unavoidable internal rainwater collection, thus reducing both the need for trades inside the building and rain damage and interference to partially complete internal works.

7.
Aerial view of Poland plant.

8. Aerial view of Thailand plant.

Design for climate

Poland has a typical central European climate with extensive cold periods during the winter. Thailand is of course very different - generally hot, with periods of very high rainfall. These differences needed a different approach to the design and detailing of the external envelope.

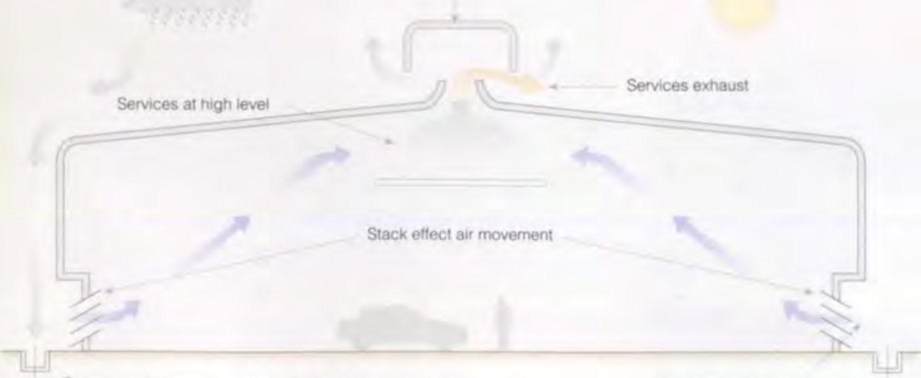
In Poland the walls have a high degree of thermal insulation, provided by traditional cassette liner trays inside and profiled metal sheeting externally, with 100mm of rockwool insulation in between. The roof construction is similar, and also gives very good insulation. In addition the most heavily-used doors in the external walls have air locks to retain heat within the factory.

In Thailand the roof contains insulation between inner and outer profiled metal skins, fulfilling two functions. Firstly it mitigates the effect of solar gain on the factory's internal temperature; secondly it provides sound insulation - the drumming of intense rain on a bare metal roof is deafening. The walls in Thailand are made from single skin profiled metal cladding without insulation, but provided with overhangs and laps to prevent rain-water or spray getting into the factory, and to allow extensive louvres at ground level for ventilation.

In Poland the design team put a penthouse at the ridge of the body shop and the assembly building, to accommodate ventilation plant and electrical switchgear. This central location for the penthouse enables good distribution of ductwork, eliminates roof penetrations for air intake and extract, and allows future plant modifications and repairs without interfering with the manufacturing production.

In Thailand, at the ridge of all production shops, a high-level monitor was provided with open sides and overhangs similar to the perimeter walls to form a continuous high ventilation slot for the full length of each shop. This combines with the low level louvres in the perimeter walls to give continuous natural ventilation by the stack effect.

9.
Overall Thailand plant design solution.



Arup made extensive calculations to determine the optimum open areas needed at the two levels, to ensure that the crossflow ventilation works across a wide range of conditions, and minimise 'dead areas' of limited air movement. Immediately below the monitor in the body shop and assembly shop is a mezzanine which houses the electrical switchgear and ventilation plant needed for process extract and to supplement the natural ventilation. Intake and extract is through the monitor walls, eliminating roof penetrations.

For both factories, the team was keen to eliminate internal rainwater pipes and valley gutters wherever possible:

- to reduce potential leakage from internal rainwater ducts
- to remove rainwater from inside the factory during construction so that floors and finishes could be built without interference from temporary rainwater control.

The roofscapes for both projects are similar and all water is shed to the perimeter of each shop. In Poland the rainwater is collected at the perimeter in conventional gutters and downpipes to run into the underground surface water drainage.

In Thailand, on the other hand, the quantity of rain-water at peak periods is too great to be collected in the conventional Western way, so the roof is curved at the eaves to make the water simply cascade off it into open drainage trenches at ground level around the perimeter of each shop.

Main text continues on page 8 ▶

Thai experiences

Local design support

Shortly after the start of work, Dynamic Engineering Consultants Co Ltd (DEC) were appointed to provide local support to the Arup team.

Their brief broadly comprised advice on local codes, standards, equipment and construction practices; detailed architectural and structural design; and the preparation and submission of all permitting information.

During construction they provided a proportion of the technical and administrative site staff.

Initially Arup's team was based in DEC's offices in Bangkok, to explain design principles, provide guidance on required standards, and monitor progress. This can be a difficult role, particularly under extreme time pressure. Technical difficulties have to be resolved within a context of diverse cultural and linguistic backgrounds, and differences in IT approach.

The inevitable flow of changed requirements can be demoralising; the challenge is to maintain a sense of common 'ownership' to achieve the joint goals. Arup was very fortunate in having a sub-consultant who supported the team throughout, and was always prepared to deal with strange 'farang' behaviour with kindly understanding and good humour.

Siteworks

On 27 November 1996, nine Buddhist monks conducted a colourful ceremony to mark the official start of construction at Rayong Province's Eastern Seaboard Industrial Estate. This lies approximately 150km south of Bangkok and is one of several that have sprung up in an area that until recently was largely agricultural. Indeed the GM-Opel site used to be part of an extensive pine-apple plantation. Today the Estate is fast justifying its claim to be 'the Detroit of the East', with both GM-Opel and Ford making major investments.

Early construction works comprised ground shaping and foundations for the press shop, all of which could be designed in detail before the main work to allow design and construction periods to overlap. The steel super-structure framing contract was also let early so that fabrication could begin before the rest of the work was let as a 'main' contract. This included all but the electrical works, which were let as a single 'global' contract covering both the Thai and Polish factories.

10.
Thailand press shop prior to press installation.

Although Thailand's construction sector is well developed and uses modern methods and equipment, for many activities there is still a widespread reliance on manual labour using quite basic tools. Many may be fashioned by the workers themselves and, although simple, are highly effective. Several homemade bicycles were also evident on the site!

For most of the year Thailand can be an extremely warm - and in the monsoon season, very wet - working environment. Although the works had been planned so that most earthworks were completed in the dry season, the site would often disappear under water during flash storms.

The intensity of lightning strikes could be awesome, frequently disrupting power supply and communications.

GM-Opel has a very strict corporate safety policy, requiring all personnel on its sites to be properly briefed and at all times to wear suitable clothing, including hard hats, safety glasses, and footwear. Senior GM-Opel management is involved in regular safety audits of all site activities, and the company treats any breach of its safety requirements very seriously.

Many workers on Thai construction sites are women taking an equal share in the day-to-day labour - in fact often doing more than their male counterparts. They are usually well protected from the sun, often swathed in headscarves topped off with a broad-brimmed straw hat. The introduction of a safety helmet and glasses on top of this protective clothing was a colourful and occasionally formidable sight.

Traditionally in Thailand every house or building should have a spirit house - a place of residence for the spirits of those who inhabited the site in former times.

12.
The spirit house in front of the administration building.

The GM-Opel plant is no exception and at a suitably auspicious time on the morning of 24 July 1998, the elaborate ceremony took place of a Brahmin priest blessing the newly-constructed spirit house. As required by tradition, it is prominent - adjacent to but out of the shade of the administration building.

Not only was a permanent spirit house constructed, but a smaller one was also erected by the construction workers between the labour camp and the main site. The importance attached to the timely construction of spirit houses encapsulates the essence of Thailand and is a reminder that even on complex industrial projects such traditional practices must be respected.

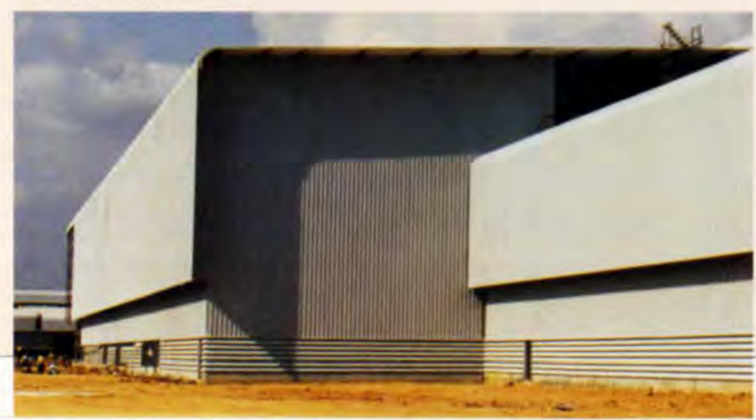
East Asia crisis

In late 1997, approximately 12 months after the groundbreaking ceremony, it became clear that the economic crisis in East Asia would have a significant impact on the project.

The economics of both the plant itself, and the vehicles that it was being built to produce, necessitated a complete reappraisal of the situation.

An initial plan to downsize' the facility to produce fewer vehicles was followed by a decision to suspend construction after achieving a 'secure and fire safe' condition. Finally an alternative manufacturing strategy was evolved to allow the plant to be completed and beneficially used, but against a considerably delayed timetable.

11.
Thailand plant:typical perimeter wall detail showing low-level louvres.



Polish experiences


13.
Poland
site preparation.

Local design support

Arup appointed a local Polish design consultant soon after its own appointment, with a similar brief to the Thai counterpart. Gliwickie Biuro Projektów Budownictwa Przemysowego was the chosen firm (GBPBP for short - even the acronym is difficult to say quickly!) - a private company originating from the local design institute. Of the many difficulties stemming from what for the local market was an unprecedentedly short timescale, the most severe were associated with the permitting processes and the use of IT production methods.

The standard permitting processes concerning both planning and technical evaluation in Poland assume that design work and all technical submittals are complete prior to submission for approval, and that a suitable consideration period is allowed before any construction starts.

This was totally incompatible with our overall programme which necessitated very early preparatory siteworks and considerable overlap between design and construction.

Negotiations with the authorities, who were extremely co-operative, resulted in arrangements that satisfied all parties. Arup particularly acknowledge GBPBP's contribution to this agreement; it would have been impossible without them.

Arup's approach involved the scheme and design development phases being done principally in Birmingham and London, with considerable input on superstructure framing in Cardiff. All work was co-ordinated from the Russelsheim project office including client reviews and instructions. Electronic production, communication methods for all data transfer and everyday project correspondence were vital. GBPBP, however, were only at the very preliminary stages of introducing CAD methods, with few computers and trained staff. With the support of Arup's Poland team GBPBP trained quickly and it is to their considerable credit that concurrently they were able to keep pace with demanding production schedules.

E-mail general correspondence was possible via the telephone network but data transfer without ISDN (continuously promised for Gliwice, but never materialised) was unsatisfactory and CD-based data and even rolls of drawings had to be used.

Siteworks

Gliwice is a town to the west of Katowice, in the heart of the Silesian coalfields in the south west of Poland. The site is on the outskirts, and the whole area is a designated special economic zone. Work started in November 1996, with contracts let in seven major packages to contractors from Poland, Austria, Belgium, and Germany.

The establishment of good site communications and relationships demanded considerable diplomatic and linguistic skills on everybody's part - and were successfully achieved.

The initial work again comprised ground shaping and press shop foundations. The ground conditions were a prime example of 'running sand' with an extremely high groundwater level.

As soon as material was excavated, water would percolate to the surface, producing fountains of water and a surface that resembled a waterbed. The earthworks could only proceed by immediately placing a geo-textile membrane and stone drainage blanket, which formed a dry working platform.

In that first winter, temperature was also a major consideration. The team had been warned of previous experiences down to -24°C for weeks. In the event temperatures only approached these levels occasionally, but nevertheless freezing ground was a major influence. The sub-zero temperatures froze the wet sand into solid blocks, which made removing the material similar to excavating sheets of rock. To maintain programme the sand that was to be used as fill was stockpiled and re-used when it had thawed out and dried in the spring. However, the extreme cold did have an advantage when excavating for the press shop basement.

The contractor had allowed for installing well points around the perimeter of the basement to control groundwater during construction, but in the event the water froze each night, forming a barrier which stopped water inflow.

As a result only a minor amount of conventional pumping from a series of sumps was necessary.

The programme for building construction inevitably required productivity levels that far exceeded local norms. A team effort by all concerned, including the client's representatives, established construction practices, information flow, checking and approval processes, and quality standards, to achieve the required dates. The first vehicle was produced, in fact, one day ahead of schedule, on 31 August 1998. It was very far from easy and had resulted from the adoption by all concerned of the 'one team' approach.

A particular technical success was the superstructure steelwork. There is clearly a particular aptitude for this in Poland. The standard of fabrication and erection was equal to anything in Western Europe and superior to most. A major problem, however, was the technical inexperience of the contractor in relation to building services and process utilities - an area where Arup had to contribute well above 'the call of duty' to maintain momentum.

14.
Poland
press shop.


15.
Car production
under way in
Poland plant.

Text continued from page 5:

To aid speedy shedding, the roof slopes in Thailand are slightly steeper than is usual in Europe, with a 6° pitch. This high pitch made it uneconomic to continue the roof slopes across all the shops, so at the junction between the assembly shop and the adjacent assembly store a valley gutter was introduced. To deal with this and the large volumes of water involved, the design team separated the buildings by 3.5m and placed a large covered drainage channel at ground level between them. A full width valley gutter is provided at high level with generous downpipes into the drainage channel at regular intervals. The valley gutter has ample width for easy access and maintenance, and is not over production areas in the shops. It is intended that this approach be used for any future extensions to the production shops.

Design for people

The social and welfare facilities for each project are quite different, mainly because of differences in working shift patterns adopted by GM-Opel in the two countries. In Thailand an extended lunch break is normal, allowing staff to rest from the heat, so here the canteen, locker rooms, medical centre, and other social and welfare facilities can be housed in a single central location because there is adequate time for employees to get there. In Poland, however, lunch breaks are much shorter; social and welfare facilities had to be dispersed around the site because the shorter break limits the time available for getting to them.

Toilets for both factories are placed to suit the greatest concentrations of people. In Poland they are typically combined with the other welfare facilities in two-storey 'pod' buildings attached to the main shops. Also in these are the extensive locker facilities needed for heavy Polish winter coats, shower facilities, and team rooms and shop offices for day-to-day meetings.

In Thailand the toilet facilities for the production shops are in small satellite structures around the perimeter of the main production buildings. If the latter expand in the future, the satellite toilets will simply be removed and rebuilt to suit.

Both plants have separate administration buildings at the respective entrances, to house management and support activities for the GM-Opel operations in the country as well as the local plant management. In Poland the administration building has conventional hot water radiators for winter and comfort cooling by fan coil units for the summer. In Thailand the high heat and humidity dictate necessitated full air-conditioning for the administration building. Also, the detailing of its finishes had to ensure that the vapour barrier is suitably located to deal with the high external humidity and relatively low internal temperatures.

Design for utility services

Both sites have a single central utilities plant which provides all hot and chilled water, cooling water for process, electrical supplies, compressed air, and fire fighting requirements. The major demand for chilled water is for the paint shops which are fully air-conditioned in both locations. Because of the high temperatures in Thailand the chilled water load is significantly higher than in Poland, and the plant and distribution pipework are consequently larger. The utility buildings were positioned to suit possible future expansion of each plant. This caused them to be in very different locations relative to the main production buildings and so the utility services distribution had to be completely different for each site. The routes were optimised using pipe bridges and the truss space in the production buildings; the fact that the pipework is up to 700mm diameter made routing and co-ordination a challenge.

Concluding thoughts

It is neither possible nor desirable to relate in an article like this the myriad of working practices developed over a large, complex project. However it is appropriate to single out key facets of the project that may inform future managers of like undertakings. Four are highlighted.

Client design reviews

It is Arup's common practice (as on this project) to implement internal design reviews of the firm's work at various stages, where solutions are audited against understanding of requirements. On the GM-Opel projects, formal design reviews were also implemented involving the clients' key leaders, including those representing that part of GM-Opel which would take over the completed facility. As with the internal reviews the purpose was to allow the technical proposals to be re-examined, but additionally it enabled the client to review 'value for money' aspects of his briefing instructions to us. The review process was also very helpful in the context of a high-speed, multilocational (indeed multilingual) project, to aid appreciation of design status.

Leadership meetings

As previously explained, key project, practice, and discipline leaders were identified, each with a clear brief. It was found, however, that with the many operating locations and pressures on people's time, a formal mechanism was needed to integrate them into a cohesive team with a common understanding and purpose. In Phase 1, this was achieved by insisting that once a month all key leaders met for a full day's mutual briefing and debriefing in Russelsheim. During Phase 2, when most activities were focused in Poland and Thailand, there were technical co-ordination meetings in the UK. In both instances the cost and effort helped keep the project on target.

Change control

Any industrial project of this kind stretching over years will experience considerable change during design and construction. This reflects the dynamic nature of manufacturing processes and the operating markets over time (eg the East Asian economic crisis), and does not show failure or incompetence. It can, however, lead to major misunderstanding and abortive effort (particularly across several locations) if there is no management of the situation. Arup believes it essential, in everybody's interest, to maintain a formal change control process with clear authorisations to instruct change, and to recognise the implications.

IT experiences

Capabilities change so rapidly that specific experiences are probably out of date before they are written. But for the record these were mixed. Within the established Arup network the capabilities to transfer data were first class and very beneficial. Between UK and Russelsheim, even to get a basic telephone line installed was difficult, and the ISDN link was achieved after great delay just as the office effectively closed. ISDN was promised in Gliwice but never materialised, and was never even promised in the district of Bangkok from where our local sub-consultant operated. ISDN into either site office was not possible. E-mail to convey short messages and provide communication glue was very effective, but as a bulk data medium was basically unsatisfactory, though it did help in one or two emergencies. Desktop visual contact (cameras on PCs conveying images of each end) was tried, but response time and picture quality were distracting to the point at which it was switched off to maintain concentration!

Carrying rolls of paper across continents proved the most effective way of tackling the working drawings issue, despite difficulties with the Polish Customs.

Credits

Client:
Adam Opel AG

Owners:
Opel Polska
General Motors Thailand Ltd

Engineer and architect:
Arup Davar Abi-Zadeh, Munir Al-Hashimim, Susie Allison, Jolyon Antill, Hilary Armstrong, Michael Armstrong, Simon Averill, David Badger, Richard Bailey, Bob Barratt, Mark Bartlett, Richard Bartlett, Dave Beattie, Keith Beckett, Ray Bennett, Steven Berry, Susanna Bickford, Barbara Bissmire, Natalie Bissmire, Bill Blake, Graham Bolton, Ian Booth, Alexander Boud, Daniel Brace, Fergal Brennan, Andy Brooks, Abigail Brooks, Vladek Brzozowski, Lyudmila Burke, Terry Burns, Volker Buscher, Joe Byrne, Susan Cahill, James Casson, Alan Chadwick, Jim Chatfield, John Clayton, Nils Clemmetsen, Sarah Clemmetsen, Nigel Clift, Tony Clifton, Nigel Cogger, Ian Collins, Clive Cooke, John Corbett, Trevor Cornman, Howard Corp, Florence Coupaud, Clare Courtney, Stuart Cowan, David Cross, Keith Crothers, Mark Davidson, Andy Davies, Joanna Davis, Leslie Dep, Asha Devi, James Dickson, Jennifer Dimambro, Richard Edwards, Osama El Garv, Philip Elliott, David Ellis, Khaled Elsheikh, Lynne Emms, Iain Evans, Michael Evans, Peter Everitt, John Excell, Jide Fakoya, Ian Fenner, Shirley Finch, Debbie Fitt, Nigel Fletcher, Kirsten Flierdl, Lee Gallagher, Gillian Gardiner, Steven Gazeley, Sara George, Rory Gibbons, Karl Gilbert, Lee Gill, Steven Gilpin, Tony Greenfield, Tony Greenstock, Geoffrey Griffiths, Andrew Gromadzki, Mike Hall, Terrie Hall, Thomas Hambley, Anthea Hampson, Jim Hannon, Neil Harrison, Alan Hart, John Harvey, Mike Hastings, John Henderson, Jane Heslington, Christopher Hewitt, Robert Hills, Trevor Hodgson, Stuart Hood, James Hornby, Dave Howlett, Pauline Hughes, John Hunt, Robert Hyde, Glen Irwin, Linda Jackson, Richard Jackson, Kasia Janusz, Martin Jennings, Scott Johnson, Chris Jones, David Kane, Alex Kania-Suchanska, Mush Kazi, John Kellett, Neil Kelsall, Akram Khan, Tania Khawaya, David Killion, Andy King, James Kirby Daniel Koopman, Andrew Kozlowski, Sophia Kral, Melody Lam, Tony Larcombe, Adam Latchford, Mark Lay, Paul Leach, Sam Lee, David Lerrigo, Julie Lerrigo, Kryssy Lewandowski, Alex Lewis, Robert Lindsay, Chris Lines, David Lister, Mark Little, Marek Litwin, Carol Lloyd, Andy Lloyd, Paul Longhurst, Colin Magner, Mani Manivannan, Chris Mann, Brian Marriott, Chris Marshall, Richard Marzec, Carol Matthews, Andrew McCulloch, Dennis McEwan, Steve McKechnie, Paul Meredith, Barbara Miller, Ian Miller, Strachan Mitchell, Andrea Molloy, Philip Monypenny, Chris Moore, John Moore, Marline Morrison, Steven Morrison, Paul Murphy, Colin Naish, John Nash, Peter Neville, Paul Nottage, Steven Olive, Nick Olson, Simon Owen, Matthew Palmer, Val Pavlovic, Andy Payne, Craig Pearce, Steve Pennington, Alf Perry, Roger Pickwick, Sandra Porter, Stephen Porter, Brenda Powell, Chris Priestnell, Oonagh Read, Toby Read, Rebecca Rhys, Winston Riby-Williams, Graeme Robinson, Denise Rogers, Brian Rogers, Diane Sadleir, Adrian Salter, Peter Samain, Kerry Sanders, Mark Sanford, John Sanford, Wal Scarr, Keith Seago, Richard Seago, Erica Seddon, Ken Sharp, Brian Shepherd, Will Sims, Andrzej Sitko, Heather Smith, Jo Smith, Lee Smith, Richard Smith, Steve Smith, June Spillane, Ewa Spohn, David Stanley, Mac Stewart, Geoff Styles, Mikka Styles, Sasi Suresh, Paul Swannell, Matt Taylor, Peter Terry, Julian Thew, Nick Thompson, Peter Thompson, Adam Tomas, Jason Trenchfield, Adam Trojanowski, Alan Turner, David Turner, Michael Underhay, Roger Vincer, James Watts, Jared Waugh, Steve Wayt, Stewart Weathers, Chris Webb, George Webb, Brian Webster, Mel West, Harry Whitby, Duncan White, David Whittleton, Martin Wilkinson, Dot Williams, Paula Wilson, Kan Wong, Katie Wood, Stuart Woods, Ronald Wooller, R Wraithmell, Stuart Yalden, Gareth Young, James Zilz

Architectural sub-consultants:
Mason Richards Partnership
[Scheme, and administration building, Poland]
Weedon Partnership
[Scheme, and social facilities building, Thailand]
Percy Thomas Partnership
[Administration building, Thailand]

Local architect / engineer sub-consultants:
GBPBP Projprzem, Gliwice
Dynamic Engineering Consultants Co Ltd, Bangkok

Programme manager:
Morrison Knudsen Inc

Principal contractors, Poland:
Mosostal Zarbze
Seimens
Porr
CFE

Principal contractors Thailand:
Christiani & Neilsen
Seimens
Sino Thai Engineering Co Ltd
Icon Construction

Illustrations:
1-6, 9: Penny Rees
7: GM-Opel
8: Morrison Knudson
10, 11, 12: Brian Marriott
13, 14: Arup
15: Elzbieta Kaliszewska

EIA study: Ngezi opencast platinum mine, Zimbabwe

Chris Carter

1.
The plateau location of the opencast mine, from Ngezi Recreational Park.

Introduction

This article records some of the achievements, opportunities, difficulties, and solutions the Arup team experienced and developed during its Environmental Impact Assessment (EIA) of the proposed Ngezi opencast platinum mine. The project - major in fee value, resources required, and shortness of programme - was an important milestone in developing environmental services in Zimbabwe.

Zimbabwe Platinum Mines (Pvt) Ltd (Zimplats Zimbabwe) is a subsidiary of Zimbabwe Platinum Mines Ltd (Zimplats), which holds various blocks of mining claims on the Great Dyke area of Zimbabwe. For the proposed mine, it undertook geological and other feasibility studies some 6km north of the Ngezi Recreational Park at the southern end of the Ngezi Project Area Base Metal Claims.

The mine, in a 158km^2 block of claims in the Kadoma administrative district 160km south-west of Harare, will produce platinum group metals, nickel, gold, and copper for at least 10 years - initially processing around 2 - 2.2M tonnes pa of rock, probably increasing eventually to a 6M-8M tonnes pa. Zimplats' pre-feasibility study indicated that it can be successfully developed, and the feasibility studies, of which the EIA was a critical part, confirmed this.

For such projects, the Ministry of Mines, Environment and Tourism (MMET) require a detailed EIA study to be completed before issuing an Approval to Proceed Certificate. The Ngezi EIA was done in line with the Zimbabwe Government's EIA policy and guidelines (MMET, 1997), so it was anticipated as being evaluated and approved by MMET's Department of Natural Resources (DNR). Steffen, Robertson, and Kirsten (SRK) partially completed an EIA study for an underground mine at Ngezi in April 1998, and DNR agreed that this could be a basis for future work and be used in preparing draft terms of reference prior to the main EIA study.

On 8 January 1999 Zimplats invited bids for the EIA study for the opencast mine from a limited number of Zimbabwe consultants, requesting a priced response by one week later. Arup's bid totalled Z$2.8M (around US$70 000), including Z$1.3M Arup fees and balance for sub-consultants' fees and disbursements.

On 22 January the contract was awarded to Arup, with the major part of the work, including submission of the EIA report to DNR, to be completed by the end of April. The time available, including scoping, public consultation and fieldwork, was thus 64 working days maximum (excluding two days' public holiday at Easter).

Programme

The EIA report was part of a broader feasibility study also including geological and hydrogeological studies, mine planning and design, process design, tailings dam site investigations and design, and a water supply study. The client's timetable was extremely tight and complex involving other specialist inputs, many of them necessary to compile the EIA. Critical dates for the Arup study are shown in Table 1.

Table 1

Activity	*Date: 1999*
Study commencement	25 January
Review of documents	25 - 29 January
Fieldwork commencement (Social scan, site visits, etc)	1 February
Delivery of draft report from sub-consultants to Arup	8 March
Delivery of final report from sub-consultants to Arup	15 March
Completion of EIA study	31 March
Zimplats review period	1 - 19 April
Study to MMET	23 April
MMET review complete by	1 June
Additional work complete by	15 June
MMET approval	30 June

The study

Human resources

The mine will operate on a three-shift basis, with workers on site for two weeks then spending a week at home; each week one shift will be bussed off-mine for the latter. After four successive rotations they will have a four-week period off, fulfilling a requirement not to exceed allowable annual working hours and including annual leave. The shifts will be 12 hours on (10 working hours, one-hour lunch break, and two half-hour tea breaks) and 12 hours off, for both management and workers.

The mine camp will be single accommodation - relatively new in Zimbabwe but well-established elsewhere. This benefits employees, who can maintain family homes in urban areas with existing educational, employment, and social opportunities. Families stay close to social services, whilst employees can spend extended periods with them for up to one third of the year.

The feasibility study examined the local working population distribution, and sources and skills levels of suitable labour. The mine was projected to employ around 300 people at start-up operational size, but after various changes, the initial core mining activities like planning and grade control will now employ 60.

To begin with there will be no major ore processing on site except for crushing. The mining production operations will be contracted out.

Opportunities for downstream mine support operations should arise within the local community.

The site environment

Topography

The site is roughly 1300m above sea level in gently undulating land on and west of the Mashava Hills, some 6km north of the Battlefields-Ngezi Recreational Park road. The southern section of the mining claims where the project is located occupies the central axis of the Great Dyke for 10km north from where it is crossed by the Ngezi River at 1220m altitude.

Geology

The Great Dyke, a simple syncline modified by cross-cutting faults, is the longest mass of mafic and ultramafic rocks in the world. From 1km to 11km wide, it traverses Zimbabwe roughly north-south for about 550km. At the present erosion levels, the remains of four elongated layered complexes - the Musengezi, Hartley, Selukwe, and Wedza - have been geologically mapped. The Hartley is the most extensive, and has been subdivided into the northern Darwendale and the southern Sebakwe sub-complexes.

The Ngezi mining claims area lies in the latter and covers the southern third of the outcrop of the overlying mafic sequence within the Hartley Complex. A zone rich in precious and base metals (the main sulphide zone) occurs in the ultramafic sequence in all four complexes and forms the economic basis for large mine developments like this.

Acid mine drainage is produced by the oxidation of sulphidic minerals in the presence of acidophilic bacteria, a process encouraged by activities like mining which expose rocks to oxidation agents.

2.
Location plan.

As a result, acidic solutions containing metallic ions are released to the environment, and water sources, aquifers, and soils may be contaminated.

Prediction of the potential of rocks to generate acid mine drainage is therefore important in developing procedures to control the short and long-term release of pollutants.

Soils

The Great Dyke soils are mostly residual black and red clays, with characteristics derived from the parent rock; there are minor deposits of alluvial soils in the watercourses. The soils near the site appear to be closely related to the underlying geology; in the granite areas, they are shallow to moderately shallow (400mm-1m) sandy loams. Black turf soils are prevalent throughout the Dyke, whilst granitic soils occur on the areas off the Dyke.

Soil investigations in the study area revealed a close relationship between the surface geology and the overlying soils, showing that most soils were derived in situ. Five soil types were identified and mapped.

Hydrology

The site is in the Ngezi River catchment, a sub-catchment of the Munyati, within the Sanyati River basin. The Ngezi is a west-flowing non-perennial episodic river that tends to form pools during the dry season where dykes cross it. South of the project area the receiving water feature downstream of the Ngezi is the Munyati, which joins the Mupfure near Copper Queen to form the Sanyati River flowing all the way to Lake Kariba. To the north are the Umsweswe and Mupfure, which drain to the west and flow into the Sanyati basin.

Hydrogeology

The depth of weathering, and presence of fractures, faults and joints, as well as the recharge potential, usually determine groundwater potential in crystalline rock terrain in Zimbabwe.

Local groundwater recharge is enhanced over the higher, forested red soil areas marking the plateau margins. Local drainage lines, especially where controlled by faulting, are also important recharge for groundwater here.

The black expanding lattice clay soils present an impervious blanket which restricts local groundwater recharge, especially in the wet season.

Vegetation

The different stratigraphic layers found throughout the Great Dyke produce distinct soils supporting different types of vegetation. The serpentine soil, covering 70% of the area, is devoid of trees, and covered by short grass. The gabbronorite areas have normal trees whilst the pyroxenite bands are often heavily wooded. There are around 20 endemic plant species, mainly occurring on the serpentine soils. Five vegetation types were identified during the field work.

Wildlife

Wildebeest, sable, waterbuck, impala, bushbuck, warthog, black-backed jackal, vervet monkey, scrub hare, yellow-spotted dassie, slender mongoose, zebra, reedbuck, and cows were all observed.

The grassland between the two hill ridges in the mine site-park boundary is ideal for game. This area is surrounded by hills and so is well protected and has palatable grasses.

The Parks and Wild Life Act (1996) classifies nine species as specially protected. One, the pangolin, occurs in Ngezi Recreational Park, whilst the aardwolf has occasionally seen in the area. Black and white rhino occur in the Midlands Conservancy, the nearest boundary of which is some 10-15km from the park, but the conservancy is probably far enough from the mine area not to be affected by it. Two of the 'big five' species, the leopard and the hippo, occur in the park and are the only dangerous game.

Archaeological and cultural sites

The field visit found mostly Middle Stone Age deposits along the western slopes and margins of the main ridge of the Great Dyke, plus some farming community settlements along the western slopes probably dating from the mid-to-late 2nd millennium AD. Typical Middle Stone Age finds included radial cores, faceted platforms, large scrapers, and a few blades and points. Two sites of very collapsed dry stone walling were found on the lower south-western slopes of the open cast. A relatively extensive farming community settlement was found close to the Gwazana River and there is also a later site with dry stone walling and lintelled windows on the north-eastern side of the open cast. These are historically significant and previously unrecorded. In the first attempt to exploit the area's platinum reserves, W Jamieson dug an adit in the 1950s. Anthills with potsherds on them, on the ridge where the mine plant is to be built, may have been used for burials associated with the settlement.

Socio-economic environment

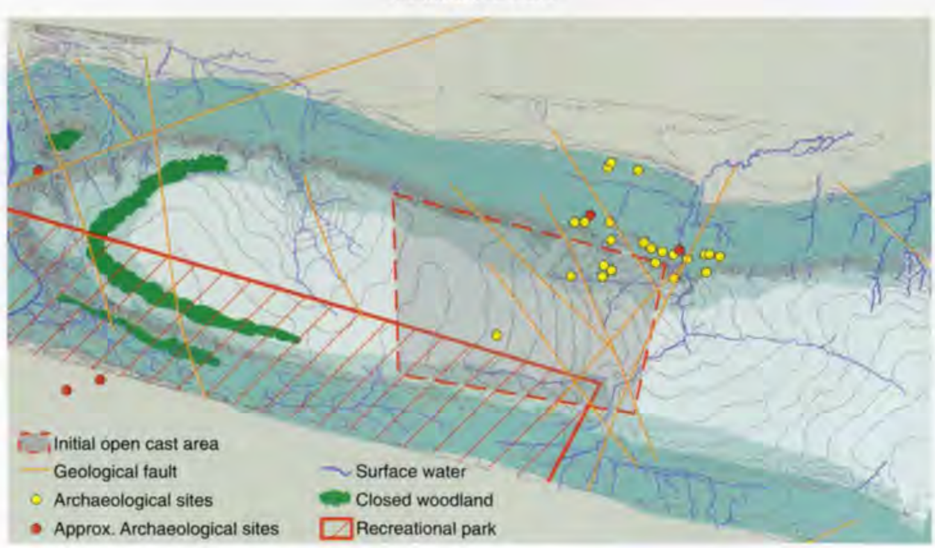
The 1992 Census recorded high population concentrations in the Mhondoro and Ngezi Communal reserves with 48 000+ and 32 000+ people and 10 and 11 households per km^2 respectively, and an average of 5.2 people per household. In rural areas females tend to outnumber males owing to Zimbabwe's long-established trend of males migrating first to seek employment in urban areas. A key feature of the distribution pattern for both reserves is the tendency for the highest concentrations to be close to the Great Dyke. Zimbabwe's harsh economic conditions, particularly in urban areas, have made urban-rural migration one of the commonest survival strategies, leading to increased pressure on rural resources. Very strong social, economic, cultural, and religious ties are maintained with the rural folk.

Findings of the study

Several potentially significant environmental impacts and constraints were identified, particularly on local surface water quality, vegetation, archaeological resources, local peoples, and Ngezi Recreational Park.

The EIA described a range of mitigation and control measures, adoption of which, with implementation of Zimplats' stated environmental policy objectives and various regulatory bodies' involvement, should ensure that the environmental effects of the mine, from construction through operation to decommissioning and closure, are contained within legal and best practice limits.

3.
The site environment.



4.
Entrance to adit dug in the 1950s.

Lessons of the study

Meeting deadlines

The client imposed tight deadlines, and the requirement for information from other studies made Arup's own even tighter. For some areas of the EIA, information had not been received from the other client specialist teams before Arup had to deliver their final report, so it was agreed with the client that the report delivered on 31 March would contain all the available information received and Arup's assessment of it, but be deemed a draft. In it Arup would clearly identify outstanding work and the date by which completion was expected. The 'First Draft Report' was thus handed to the client on 31 March on programme.

Information from mining specialists appointed by Zimplats was critical to completion of the EIA study, but the final report on the mine plant and operating plan was not received for more than a month after the date originally programmed.

This caused major problems in completing the assessment and compiling the EIA Report.

Zimplats completed the review of the first draft ahead of programme and a second draft was requested by the client and delivered on 19 April 1999. Following further comments the Draft Final Report was delivered to Zimplats and DNR on 30 April 1999, in line with the original programme.

Project management

To address various issues, Arup employed sub-consultants to carry out field work and provide specialist inputs:

- Geckoconsult (ecology, flora and fauna, eco-tourism)
- National Museums and Monuments (archaeology)
- UZ Mining Dept (mining operations, noise, health and safety, air quality)
- DPC Professionals (socio-economic issues, social scan and IAP consultations, feedback)
- Soils Inc (soils and land quality).

Other studies also contributed to the EIA; a client contractual arrangement allowed Arup to employ members of other feasibility teams to provide information at cost+10%. Jeremy Prince & Associates was appointed to extend the geology and hydrogeology studies and obtain groundwater samples from within the study area. Stewart Scott (Zimbabwe) provided information and chemical analysis data on surface water in the study area, and data on water supply, roads, and power supply arrangements. Pearce Partnership provided information on the mine village, for which they were the architect. Australian Mining Consultants (AMC) and Aptech Fluor Daniel similarly assisted with mine plant layout, mining operations and processing, chemicals and mining waste handling, disposal, and rehabilitation.

SRK (Zimbabwe) were contracted by Zimplats to compile a feasibility study for the tailings and return water dams, and supplied their findings.

Arup's project manager was responsible for 12 individuals from the external sub-consultants, six Arup specialists, and liaison with five other feasibility study teams. As well as regular study team meetings at critical stages, Arup instituted a weekly arrangement for reporting project status, study team needs, planned and completed site visits, etc, requesting all sub-consultants to report progress to a specified format. The results were circulated weekly to sub-consultants' representatives. These meetings and reports were important to keep the project moving, identify problems before they became critical, report to the client on progress, and increase contacts and information exchange between team members.

Document and file management

The number of documents received at the start of the project from the client was relatively small. These included draft terms of reference for the opencast mine, compiled by SRK following the underground mine EIA. However, as the project progressed and the delivery dates for reports from sub-consultants and other feasibility study members were approached, the flow of information became a flood. Hard copies of reports arrived from various sub-consultants and the client. Electronic copies of reports and drawings were received on disk or by e-mail. All this information had to be recorded as received, assessed as adequate and passed on to the relevant team member for assessment or inclusion as a report or drawing.

Compilation of the report

The basic layout Arup proposed for a previous EIA was adopted here, with additional tabulation of critical issues arising from the impact assessment and the selection of mitigation options. Tables in a standard format were used for each subject (ecology, socio-economics, etc) identifying the issue or effect, its description, possible mitigation measures, and highlighting potentially significant impacts after mitigation. The three-volume EIA was compiled and completed on time and budget.

Conclusions

The study was a major project for Arup Environmental, Harare, and several important lessons were learned from the way it developed and was managed. These embraced software considerations, contractual arrangements, the development of team-working skills and measures for information exchange, and the recognition and encouragement of preferred roles of the core team members. DNR approved the EIA on 28 June 1999 and trial mining was completed successfully at the end of 1999. The project, though somewhat changed from the original plan described in the EIA as a result of political and financial developments since it was approved, is now on the verge of operations.

Arup Africa is actively pursuing work in mining in Africa. The industry is a major contributor to the economy of many African countries. Arup's contacts and clients, many of them well-established multinationals, seem to appreciate the firm's multidisciplinary approach. The EIA study for the Zimplats Ngezi opencast platinum mine has led to further work on road design and construction for the same client and new opportunities in this field are anticipated.

5.
Partially coursed drystone walling.

Credits

Client:
Zimbabwe Platinum Mines Ltd (Zimplats)

Consultants:
Ove Arup & Partners Zimbabwe
Chris Carter, Joseph Chihota, Chris Furukiya, Andy Marks, Paul McCullough, Miki Milanovic, Louis Steenbok, Mitch Tunikowski, Sharon Waterworth

Sub-consultants:
Geckoconsult
National Museums and Monuments
University of Zimbabwe Mining Dept
DPC Professionals
Soils Inc
Jeremy Prince & Associates
Stewart Scott (Zimbabwe)
Pearce Partnership
Australian Mining Consultants (AMC)
Aptech Fluor Daniel

Illustrations:
1: Geckoconsult
2, 3: Penny Rees / Sean McDermott
4, 5: Lorraine Swan

The ACAD project

Mike Booth Allan Iles Peter Kinson Andrew Minson

1 ACAD Centre:
Glazed staircase in mall.

Introduction

The Ambulatory Care And Diagnostic (ACAD) Centre recently completed in Park Royal, north-west London, is the nearest thing to a production-line hospital in the UK. Designed as a 'one-stop shop', the 8000m^2 building houses four operating theatres and a full complement of digital X-ray equipment, an MRI scanner, and endoscopy facilities, together with treatment rooms and consultants' offices. There are, however, no wards, only recovery bays, and all patients are booked in by appointment so that waiting times are minimal.

Radical ideas thus underpin the design of ACAD:

- Elective health care and emergency care should be separate entities.
- Flexible design is essential to accommodate future innovation in both equipment and procedures.
- Quality of space is important.
- A hospital does not need beds.
- Private Finance Initiative (PFI).

Clearly the ACAD centre represents a ground-breaking move for Britain's National Health Service, and the radical ideas have been so successfully implemented that it was awarded a Millennium Product Design Award. When opening the centre in September 1999, Prime Minister Tony Blair commented '*It is a marvellous concept and a vision that has been transformed into quite a stunning reality.* [It] *is the future for the Health Service.*'

Design concept

The client, the Central Middlesex Hospital NHS Trust (CMH), adopted the basic strategy of separating elective care from emergency care - possible because of the latest high technology diagnostic equipment and minimally invasive techniques. It recognises that elective healthcare can be free from expensive and inappropriate in-patient services: it can be 'walk in-walk out' (ambulatory).

The building design therefore emphasises the importance of public spaces in a hospital where patients are mobile and conscious, as well as the need for flexibility as technology develops and healthcare demands change.

Medical specialisms are brought closer together rather than dividing into departments.

Patients can travel through the building receiving treatment without ever having to re-trace their steps. This linear sequence of spaces avoids subjecting new patients to the possibly unnerving experience of crossing with newly-treated patients wearing bandages or slightly disorientated. It also allows those who may have received bad news to leave the building discreetly.

Integral to the design concept is high-speed electronic information transfer and storage, whereby virtual folders are filled with digital, high-resolution images and patient notes as patients move through the centre. A patient's scanned images will have reached the consultant's room well before the patient has had time to walk there. These images can then be sent electronically to the patient's doctor if necessary.

At the early design stages Arup worked closely with the architects to formulate the strategy for the hospital.

The design evolved through these early workshops. The main aims were to achieve a flexible, efficient, and economic space that could easily respond to changes in healthcare. Arup proposed a clearly defined vertical and horizontal strategy, a structured wiring system, and regular column grids with secondary services distribution on grid lines. The overall layout of the building, with 'high technology spaces' on one side of a mall and the 'low' technology on the other, was a response to the servicing needs. This allowed separation of spaces needing full air-conditioning and little daylight from those requiring minimal ventilation and maximum daylight. The strategy was developed considering both architectural and engineering needs.

Procurement

The design team was appointed following selection from a closed competition in March 1995. Avanti Architects, whose portfolio at the time typically included smaller health projects, had invited Arup to join them and provide multi-disciplinary engineering advice. The original concept was for the specialist medical equipment, the software and hardware backing it up, and the facilities management to be provided as part of a PFI collaboration. This includes a comprehensive structured wiring network supporting both voice and data as well as mechanical controls, security, and fire.

The software transmits the patient information and picture archiving systems, and allows airline-style booking of appointments and checking-in of patients. Honeywell Control Systems and Philips Medical Equipment were identified as the preferred partners, and although some of these items transferred into the building contract, the strategy remained intact.

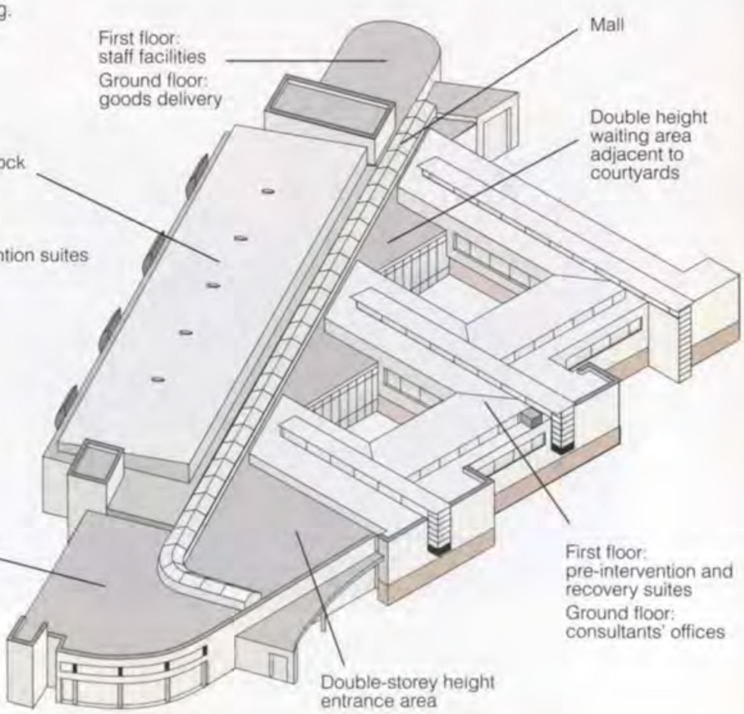
The building contract was a traditional English *GC Works 1, Edition 3* format modified to suit the PFI element of work. Tender documentation was issued in April 1997.

Structure

The triangular site (140m x 120m x 75m) is on the perimeter of the CMH grounds and was previously occupied by an assortment of low-rise temporary hospital buildings. The level site had up to 1m of made ground overlaying London Clay weathered to a maximum depth of 7.5m. Some small pockets of predictable contamination were cleared prior to commencement of the new works.

The structure is two and three storeys high, founded on shallow footings, and has no basement. To keep differential settlements within acceptable limits, 0.75m deep mass concrete pads were cast beneath reinforced concrete pads. Between these, a network of ground and edge beams support the 200mm thick ground level slab, designed as ground-bearing under self-weight and suspended under live load to maximise structural efficiency.

2.
Layout of the building.



Imaging equipment required an allowance of up to 94kN in existing and future imaging rooms and on the installation / removal route (as well as knockout panels in the façade for future replacement).

The ambulatory aspect of the building's function meant that special attention was given to entrance, circulation, and waiting areas. A double-storey height zone forms the entrance, from which a 4m wide, 10m high mall extends the length of the building. Its glazed roof provides light to the heart of the building. Twice along its length, the mall widens out into 7m high waiting areas, each with full-height, 14m wide glazed walls giving views to the courtyards.

The mall itself forms a movement joint between structures, the proprietary glazed system over it being fixed on one side and sliding above the other. Since the duopitch framed glazing system has a pin along its ridge, regular ties between supports are required to prevent spreading. The mall roof is protected from net uplift by being distant from the building roof edge. On one side of the mall, there are movement joints at either end of the three-storey zone. Details in the mall glazing accommodate relative movements arising from these joints.

The reinforced concrete superstructure is typically on a 7.5m x 7m grid. At first floor level it comprises multi-span 275mm deep ribbed slabs spanning onto two and three-span 375mm deep x 1.5m wide beams, which act with 300mm x 300mm columns to form sway frames across the structures. Multiple bay sway frames along each structure utilise 275mm deep edge beams running parallel with the ribbed slab. The shallow structural build-up provided large services zones and maximised the clear height between floors - particularly required in the theatres.

The floor structure was designed for the future flexibility needed in a hospital building and allows for:

- heavy blockwork loading (2.5kN/m^2)
- permanent void formers within wide beams for future services penetrations
- potential breaking out of topping between ribs.

The second floor plantroom is above the theatres. Its 350mm flat slab allows for large service penetrations as well as providing a flat soffit for services distribution and a good acoustic barrier. The plantroom roof is a steel portal frame, but elsewhere trusses (formed from back-to-back angles) span 11m. These trusses form a duopitch ceiling and roofline, with a clerestory along the ridge allowing light and spaciousness in preparation and recovery rooms. In addition the trusses accommodate services runs through the roof space.

Mechanical

Hospitals' extensive ventilation needs traditionally are provided both naturally and mechanically, the latter normally being limited to areas with clinical or functional need; for staff and patient comfort; to control substances hazardous to health; and to satisfy equipment manufacturers' requirements. To keep energy costs down, remaining areas are usually naturally ventilated. However, with new safety and security requirements limiting openings sizes, increased use of heat-producing equipment, and internal partitioning severely impeding airflow paths, successful naturally-ventilated inner city hospitals are more difficult to achieve.

NHS studies have indicated reduced summer levels of staff absenteeism, accidents, and fatigue amongst staff working in departments providing more environmental comfort. Indeed, both patients and staff now expect a reasonable degree of comfort. CMH, in commissioning the ACAD building, required a system flexible enough not to restrict but be adaptable to operation planning and provide a high level of environmental comfort for staff and patients.

3
Eastern elevation.

The building is ventilated by individual air-handling plant (AHUs) located in the roof plantroom in the high tech block, and is zoned along department lines, floor by floor and wing by wing, allowing independent hours of operation and control.

The Intervention department is divided into several suites, each containing two theatres. A single AHU, per suite, incorporating split decks enables each theatre to have individual temperature and humidity control. Air movement in each suite is arranged with descending pressure control utilising multi-bladed pressure stabilisers, so that airflow is always away from the cleanest areas towards the less clean spaces. All ventilation plants operate on full fresh air except for the units serving the Imaging and Administration departments where some recirculation is permitted and a VAV system has been provided. Heat recovery, by plate exchangers arranged with positive pressure within the supply section, is incorporated within each full fresh air unit. The VAV units are provided with enthalpy control.

As well as general extract, dirty extract systems are also provided. Local systems serve the endoscopy instrument cleaning, MRI helium discharge, and dental lab extraction. Anaesthetic gas scavenging systems are installed in the theatre suites.

The primary heat source is steam, from the hospital central boiler plant; condensate is collected and returned there by steam-driven pumps. Plate heat exchangers in the ground floor calorifier room transfer heat from the steam supply to low pressure hot water circuits providing constant temperature to the AHUs and reheater batteries with variable temperature to radiators and emitters. Domestic hot water comes from storage calorifiers, with steam as the primary heat source.

A reduced pressure supply from the steam main provides the humidification requirement within the Intervention suites.

Cooling is from local air-cooled packaged refrigeration units in a screened enclosure adjacent to the roof plantroom. Chilled water pumps, pressure set, and buffer vessel are in the AHU roof plantroom.

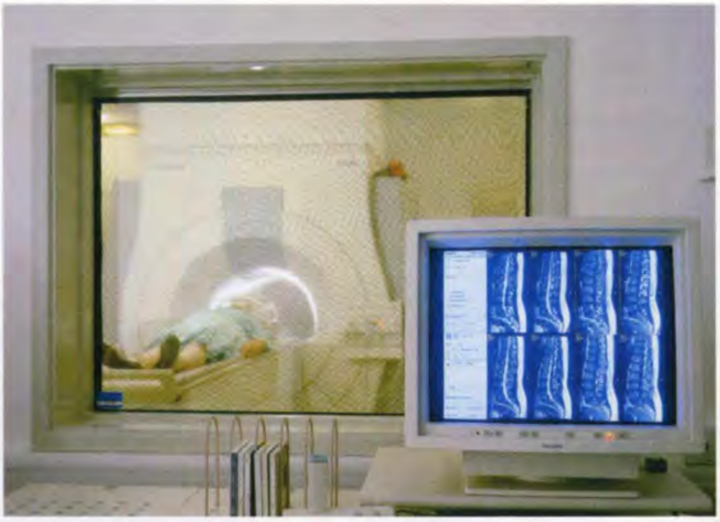
The chiller units, arranged in parallel, provide constant chilled water for dehumidification and comfort cooling of the building.

A self-contained packaged chiller unit provides standby cooling of the MRI magnet assembly.

All the plant is controlled by a Building Management System, incorporating a full graphical interface specific to the actual building layout and plant components provided for each system.

4.
The double height entrance and mall.

5.
One of four operating theatres.



6.
MRI Scanner.

Public health

The medical gases - oxygen, medical air, medical vacuum, and nitrous oxide - are piped from remote locations on the hospital site via an underground services duct. The oxygen comes from the hospital's VIE plant, the others from a packaged plantroom near the car parking area. To avoid contamination of the hospital's piped vacuum system, the dental vacuum is provided by an individual plant in each of the treatment rooms.

Domestic hot and cold water are fed from the roof plantroom storage tanks via a packed booster pump set, to ensure the required pressure at points of use. To protect against backflow, the ground and first floor areas are served from separate branches incorporating double check valves. Main branches are fitted with service valves, double check valves, and flushing points, which allow for isolating and sterilising water systems in individual areas while the remainder of the building operates normally.

Domestic hot water from storage calorifiers is circulated to points of use via secondary flow and return mains. To ease balancing of the secondary mains, the secondary return branches from individual sanitary fittings are connected together before flowing back into the main secondary return.

Because of the limited fall available to the public sewers, and to ensure that foul and surface water discharges via gravity alone, the drainage pipework runs through several ground and edge beams. The concrete reinforcement and the pipework closely co-ordinated to allow for this, particularly at the highest points in the system.

Electrical

The system was designed with full back-up capability, with single points of failure reduced to an absolute minimum due to the operational requirements of many parts of the building.
Two separate low voltage supplies were taken from the local LV network transformer chamber and two back-up generator supplies feed from the hospital main plant.

The theatres were designed with fully monitored safety-isolated supplies to stop patients being affected by equipment earth faults. The 1.5 Tesla MRI scanner room had to be shielded to prevent its large magnetic fields from affecting other areas, including computers in the adjacent control room.

The structured wiring - an enhanced version of category 5 cabling standard - goes to all areas at a minimum density of four individually wired outlets per person or space.

This allows additional components requiring communication links to be added without having to pull new cabling to the communication hubs.

The wiring is used by various systems requiring communications around the building:

- the security system, so that card readers, presence detectors, etc, can talk to the central security computer
- the mechanical controls system whereby field devices are linked to the BMS
- the traditional telephone and computer links to the PABX and hub rooms respectively
- the medical equipment links to the image storage servers, via the picture archive and patient information systems
- the patient appointment and checking-in system.

The lighting design had to allow for patients lying on trolleys looking upwards, so either uplighting or wall washing luminaires were chosen.

Another requirement was to ensure that where blood samples were to be taken, the correct colour temperature lamps were specified so that veins below the skin could be seen.

Conclusion

Construction commenced in July 1997.

Following three months' commissioning, ACAD was handed over to the hospital in February 1999 for three months of medical fit-out, prior to accepting its first patients. The building was completed on time (78 weeks) and to budget (£10.9M) - a success story for a complex building of this nature. This was primarily as a result of stringent change order control by the project manager, supported by the design team, and a refusal by the client representative to implement any changes stemming from the client body during the post-tender phase.

Credits

Client:
Central Middlesex Hospital NHS Trust

Architect:
Avanti Architects

Structural, MEP, and geotechnical engineers:
Arup Geoff Balrow, Mike Booth, Fiona Cousins, Jim Fleming, Heather Grose, Alistair Guthrie, Bob Hide, Allan Iles, Phil Jordan, Peter Kinson, David Mills, Andrew Minson, Heleni Pantelidou, Colin Wright

Quantity surveyor:
James Nisbet & Partners

Main contractor:
John Laing Construction

M&E contractor:
Haden Young

Specialist services contractor:
Honeywell Control Systems

Illustrations:
1, 3-7: Nicholas Kane
2: Jonothan Carver

7.
Recovery Bay.

Warburg Dillon Read, 1 Finsbury Avenue, London

Mick Brundle Iain Lyall

Introduction

1 Finsbury Avenue was completed in 1984 - the first of a three-phase office development designed by Arup Associates for Rosehaugh Greycoat Estates[1]. The 50 000m² building is eight storeys high and was designed around a full-height central glazed atrium, capped with a large glazed lantern to allow occupiers to benefit from as much daylight as possible. At the same time, it was designed to be very economical in its use of energy with external shading devices to protect the building from the effects of solar gain.

A particular feature of 1 Finsbury Avenue was the design of the structure. The building has a steel frame with metal decking as permanent formwork for the concrete floors. The use of structural steelwork with sprayed fire protection allowed extremely rapid construction.

In 1986 SG Warburg became one of the building's occupiers when the firm acquired Rowe & Pitman. Over time, Warburg's presence in the building increased until it became the sole occupier. When SG Warburg and Swiss Bank Corporation merged their activities in 1995 to form SBC Warburg (SBCW) - now Warburg Dillon Read - the new company required a single City of London location to house its dealer operations. At the time the business had two locations: in Lower Thames Street and Nos 1 and 2 Finsbury Avenue - the award-winning buildings in the Broadgate development.

The original brief for the project was to provide a new dealer environment for 1200 dealers and to upgrade the firm's business process and technology, whilst increasing the resilience and robustness of the IT and building services infrastructure. All work was to be carried out with minimal disruption to the operation of the business.

A review of SBCW's options for upgrading both of the firm's sites was carried out by Arup Associates and Ove Arup & Partners. In spring 1996 the bank agreed with the recommendation that 1 and 2 Finsbury Avenue would best meet its requirements. Detailed design work began immediately and proceeded in parallel with construction, which started in August 1996. The first phase of the client areas was handed over in January 1997, with the major dealer move onto new floors and systems following in August. The final handover took place in July 1998.

1.
View from the new dealer floor.

The scheme

The key element of the brief was the client's requirement for the new dealer environment. The vision of the designers was to create a major market place at the heart of 1 Finsbury Avenue in which every dealer would feel involved in the excitement and energy generated on the dealer floor. A major constraint on the scheme was that the building's structure only allowed the atrium to be bridged at one level. SBCW had envisaged that the atrium of 1 Finsbury Avenue could be bridged at second floor level. Arup Associates, however, felt that the depth of the structure needed to form the new floor would result in the area below feeling small and mean - contrary to the client's desire for an entrance area appropriate to its standing as an international bank.

The agreed solution floored over the atrium at third floor level, creating a triple-height volume beneath, which was more in keeping with the proportions and style of the existing building. As it was impossible to daylight the hall from the atrium roof, a combination of artificial light and reflective surfaces have been used to create a corporate and social focus to the building. This is primarily used as the entrance and ground floor circulation, but is also suitable for receptions and exhibitions.

It was necessary to protect the new dealer floor from solar glare through the existing glazed 'lantern' which tops the atrium. The original plan was to install a canopy roof at fifth floor level. As the scheme took shape, however, SBCW's space requirement for dealers grew and more floor area at fourth and fifth floor level was dedicated to this function. A new 6m wide gallery inserted on all four sides of the fourth floor provided an extra 600m² of space, with the fifth floor level also fitted out for dealers. As a result, the canopy roof was moved up the building to the roof level immediately beneath the existing lantern, allowing future expansion of the dealing operations onto the sixth floor if required.

The required visual and acoustic connection to the main dealer floor on the third floor was achieved by leaving the fourth and fifth floors open above new glass balustrades. This gives the dealers the feeling of working within a single space and creates the 'buzz' of the market place that the client desired. Two new helical staircases, designed for minimal visual impact connect the dealing operations - between the third and fourth floors at the south side of the dealer floor and third, fourth and fifth at the north side. Additional space was formed to house the IT and create an 'engine room' to run the building.

2.
1 Finsbury Avenue was designed by Arup Associates for Rosehaugh Greycoat Estates, and completed in 1984.

The dealer floors - levels 3, 4, and 5: canopy

The functional requirements of the dealer floor meant that it was necessary to roof over the building at level eight (roof level). The design of the canopy, which forms the new roof, makes a fundamental contribution to the quality of the space below and to the atmosphere of the dealer floor activity. It was felt that the environment would benefit from allowing controlled daylight into the space from the glazed lantern that tops the atrium. This would not only give natural light to the occupiers of the space, but would preserve the identity of the atrium - a key design feature of the existing building.

The canopy had to fulfil five main functional design criteria; to:

(1) exclude sunlight and allow controlled daylight to the dealer floors

(2) control noise in the space

(3) act as an gantry for artificial lighting and maintenance cradle

(4) act as a second line of defence against water ingress

(5) allow smoke extract through the roof lantern as an integral part of the fire strategy.

These rendered a lightweight solution - such as a fabric tent - inappropriate, so one was sought that would meet the functional requirements whilst still being aesthetically acceptable.

The solution is a steel and glass atrium designed by Arup Associates with Arup R&D and Arup Acoustics. It was conceived as a 'kit of parts' to overcome the limits that the existing building imposed on the size of members that could be installed.

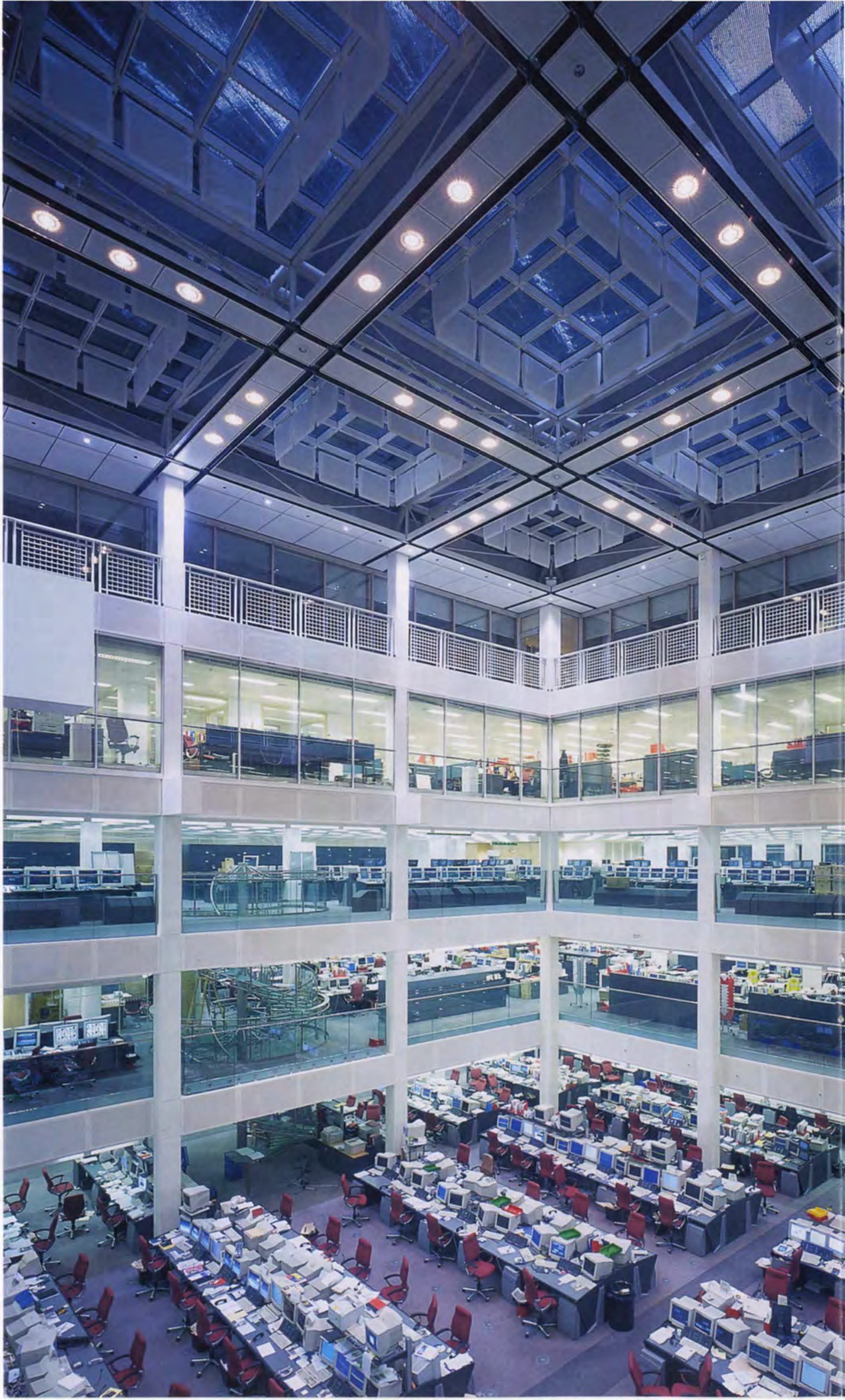
A tartan grid of steelwork is infilled with pre-assembled double-glazed units with an encapsulated 'micro louvre' sandwiched between the two panes of glass. The 'micro louvre' - the construction of which resembles a zigzag egg box - is chrome-dipped and orientated to allow north light through the canopy whilst reflecting south light, thereby protecting the dealers from solar glare. The 'micro louvre' does not obstruct views, so the atrium canopy is clearly visible from within the dealer floor, as is the changing sky.

To meet the requirement for the canopy to be accessible for cleaning and maintenance, a grid of walkway gratings runs between the columns of the building. These gratings exclude sunlight and allow access to gutter assemblies suspended below, which contain luminaires in perforated aluminium ceiling panels. Between each of the gutter assemblies, several acoustic absorbers are hung from the steelwork grid to provide the desired noise control. The tartan structural grid also acts as a 'rail system' for a suspended cleaning cradle.

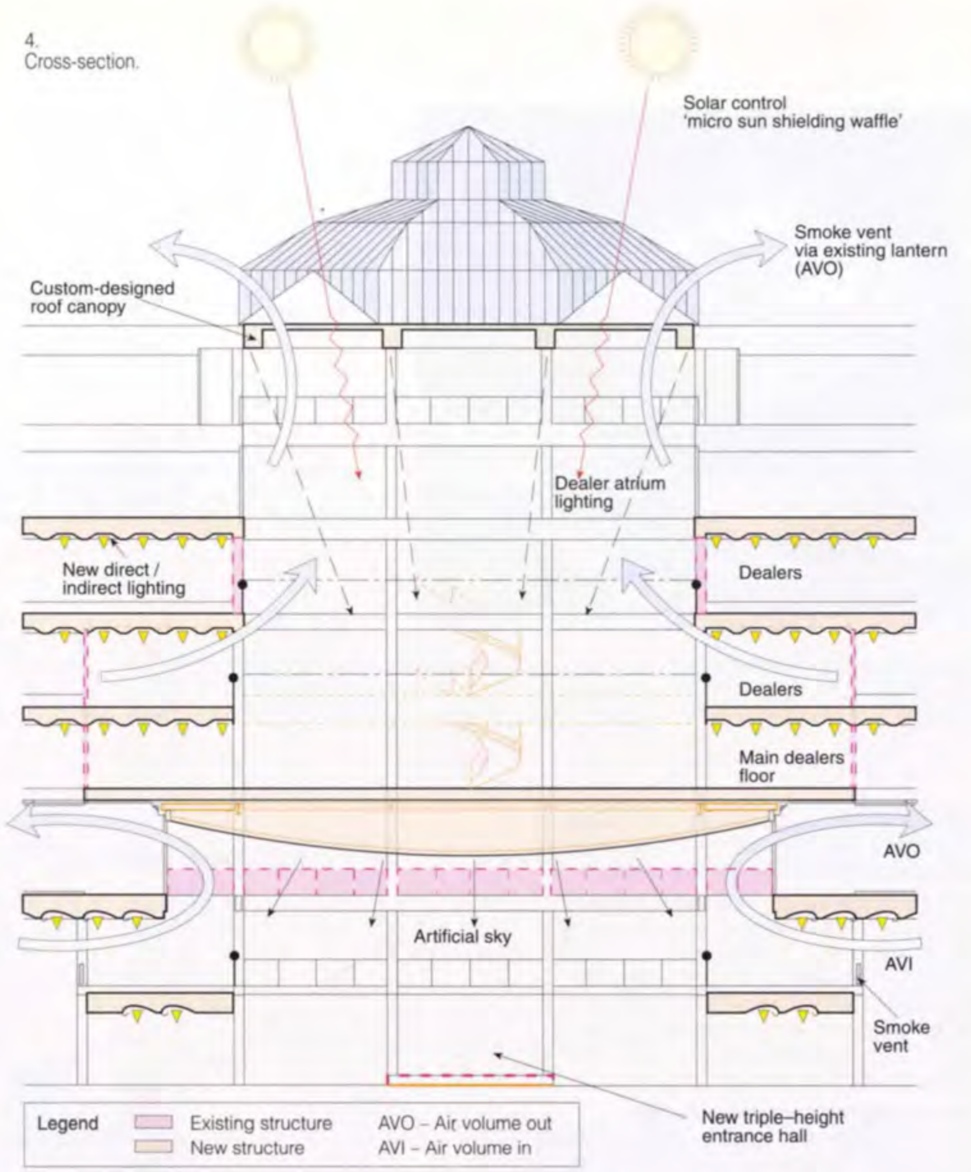
3.
The brief's key element was provision of a dealer room for 1200 dealers.

It sits on the third floor at the bottom of a five-storey volume.

The fourth and fifth floors house more dealers and are open above glass balustrades, creating the desired 'market place' environment.



4.
Cross-section.



The new hall: ceiling

Flooring over the atrium at third floor produced a triple-height entrance hall volume. As the daylight from above had been extinguished, a way of artificially lighting the space was required that would create a bright and modelled interior which could be varied to suit different functions.
The new ceiling is a 576m^2 translucent bowl of glass, backlit by a grid of individually controlled fluorescent luminaires which uplight the ceiling void and provide an overall coloured diffuse light. Concealed downlighters provide additional light at the hall base.

These sources are controlled to allow a variety of lighting environments either timed sequentially during the day, or memorised to set a lit theatrical 'scene' for special functions. This 'artificial sky' consists of a series of translucent glass tiles individually suspended from the soffitt of the dealer floor slab above. Each tile is suspended from a specially designed cast stainless steel 'spider' fixing. This enables each piece of glass to be set at a variable geometry, whilst allowing unlocking and hinging for access to the lighting, control and detection systems in the ceiling void above.

The geometry of the curved ceiling follows closely the curved structural profile of the twin primary beams which support the dealer floors, a geometry which is repeated perpendicular to the beam line, forming a ceiling profile of a deep bowl at the centre feathering off to level at the perimeter.

The glass tiles are 'floating' with a 50mm gap on all edges. This enables the ceiling shape to be easily formed, allows return air to pass through the ceiling, and gives access to the concealed unlocking mechanism that allows the tiles to be hinged open.

Engineering

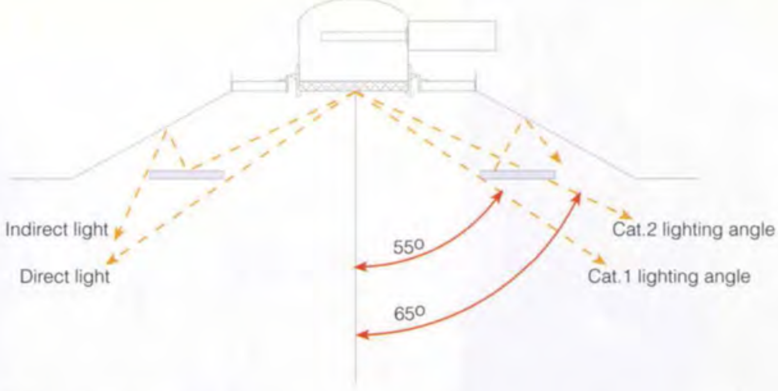
The new combined dealer operation and additional conference and dining facilities significantly increased the building occupancy.

The base building variable air handling plant was upgraded to provide increased outside air for ventilation. This involved larger cooling coils and damper modifications. As a result the two 1.2MW base building water-cooled centrifugal chillers, operating on CFC refrigerant R11, were replaced with two 1.5MW R134a units. This changeover took place during the winter of 1996/7, using the free cooling cycle on the VAV plants to maintain conditions in the building.

Four new IT risers and four new power risers were cut through the building from basement to roof with work being undertaken at night and weekends without disrupting users. New 24-hour cooling risers were also installed at the same time. The new IT and occupancy loads were predicted to need cooling of 2.4MW, in addition to the base building 3.0MW and the original 24-hour system of 0.9MW. This gave a total installed cooling capacity of 7.5MW. Three new air-cooled chillers, each rated at 1.2MW, were installed on the roof giving N+1 capacity for resilience. All of the engineering hardware and systems were installed using this N+1 philosophy to meet the requirement that a single point of failure would allow seamless operation of the trading facility.

The original building was designed in the early 1980s before large-scale electronic trading was considered in building design, so the insertion of the gallery floor at fourth floor level resulted in a restricted floor-to-ceiling height. Very high cooling loads gave large air volumes, and the desire for ▶

5.
The specially designed luminaires for the dealer floor combine the recommended provision for VDU use with an uplit ceiling from a single standard fitting. This increases the apparent height of the space and avoids the gloomy interior that can result from sole use of a Category 1 luminaire.



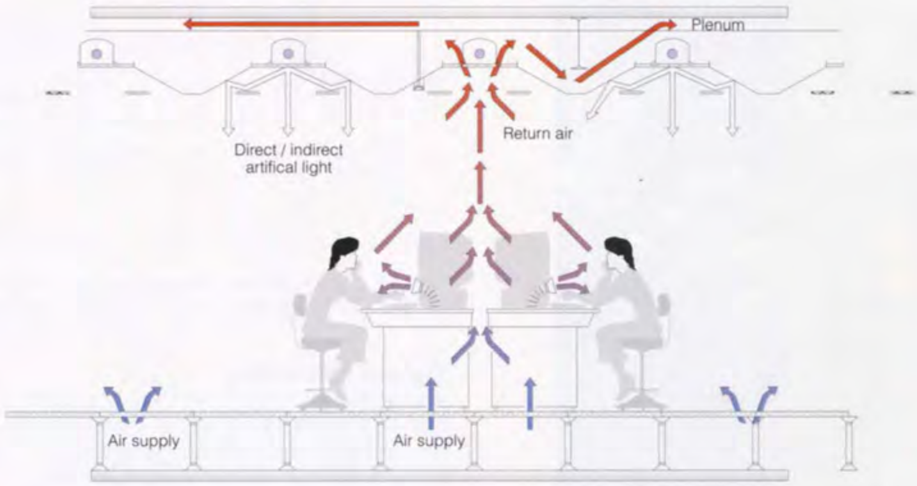
6.
The custom-designed light fittings comprise a standard CIBSE category 2 luminaire and a micro-perforated spun diffusing ring, which limits the downward component to the equivalent of a Category 1 luminaire whilst reflecting the wider Category 2 light onto the coffered ceiling.

structured cabling for power and IT on a 1.8m grid demanded a deep floor void to maintain reliable comfort conditions on the new dealer floor.

An underfloor air supply system was designed which uses the floor void as a supply air plenum (as well as for power and IT) and the ceiling void as the return air plenum. This system removed the need for ductwork, chilled water pipes, and condensate drains, and has proved to be an economic and quick solution to the problem of servicing levels three and four.

The ceiling and luminaire design

Using this system did, however, result in an overall floor depth of 450mm to accommodate air and cable services. This is 200mm higher than the level in the existing building and would have resulted in an unacceptable floor-to-ceiling height if the existing ceiling line had been retained. The solution was to raise the ceiling height by 200mm, made possible as the ceiling became just a plenum void with sprinklers and lights. The depth of the steel beams and minimum plenum depth imposed the only limits on the ceiling height. The area between the beams has, therefore, been raised further to create a coffered profile.



7.
High IT equipment loads are accommodated within the occupied space by adopting an underfloor air distribution system with the air return via a ceiling plenum. Air is discharged directly into a 'sealed' IT zone at the base of the dealing desk to cool the processors, and exits through a slot directly below the rear of the IT screens.

8 (a-d).
Believed to be the largest installation of its kind in Europe, the 'artificial sky' is a 576m² translucent bowl formed of individually suspended glass tiles.

(a)

(b)

The light fittings are contained within the raised coffers. These are custom-designed and comprise a standard Category 2 luminaire and a micro-perforated spun diffusing ring. The diffusing ring limits the downlight angle to the equivalent of a Category 1 luminaire whilst also reflecting the wider Category 2 light up onto the coffered ceiling. In this way, the recommended downlight provision for VDU use is combined with an uplit ceiling from a single standard fitting. The resultant effect increases the apparent height and generosity of the space. The consistent glow given off by the fittings avoids the creation of a gloomy interior that often results from the sole use of a Category 1 fitting.

Using the floor void for the distribution of cooling and ventilation air has many advantages apart from maximising the available storey height. Integrating air supply outlets into the dealer desk design has enabled cooling air to be discharged directly into the equipment compartment of the desk to cool the processors. This air is then discharged through a slot at the back of the desk, capturing the heat produced by the screens. The plume of warm air then rises rapidly to ceiling level and out of the occupied space. Additional swirl type floor outlets were used in and around the seating and circulation areas to provide users with their own micro climate and the ability to make some personal adjustment.

Extensive computational fluid dynamics studies were carried out to establish optimum airflows and temperatures with different desk and outlet configurations. Final proving was by laboratory thermal modelling using prototype dealer desks. The solution allows rapid changes in desk layout without any air conditioning modifications.

The under-desk air outlet incorporated the power and data cabling entry from the floor void to the desk. Simple relocation of the outlet tile is all that is necessary to reconfigure the services provision to the desk.

On a typical dealing floor, cooling is supplied by 12 downflow units, with an additional four units serving the third floor infill. These units are arranged in eight zones for temperature control. They draw air from the ceiling void and directly from the space and, after filtering and cooling the air, supply into the floor void. The units are housed in acoustic enclosures, within which air supplies from the base building plant are mixed with the downflow unit discharge air.

The controls are sequenced to maintain a minimum air supply temperature to the floor void of 18°C and proper outside air quantities to suit the high occupancy levels.

The existing electrical supply and distribution in 1 Finsbury Avenue was approaching its limit and the additional loads demanded a complete reassessment of the electrical systems. The base building had five substations rated at 1050kVA. These were supplemented by a new substation with a capacity of 2.0MVA giving an installed capacity of 7.25MVA. To provide a resilient distribution, four new electrical risers were installed in parallel with the existing distribution. Each contained an essential generator backed riser and a UPS riser.

Conclusion

No 1 Finsbury Avenue was designed pre-'Big Bang' as a multi-tenanted building on the edge of the City of London. It pre-dated the whole of the Broadgate development and is considered to be one of the best modern office buildings in the City.

The successful transformation of the building into a highly serviced and resilient environment, suitable for the dealer market with extensive and state-of-the-art IT, was partly due to the inherent flexibility of the original design, and was achieved whilst the building was occupied and fully operational, without the loss of a day's trading.

9.
Staircase between 3rd and 4th floor.

Reference

(1) ARUP ASSOCIATES GROUP 2. 1 Finsbury Avenue, London: Phase 1. *The Arup Journal, 21*(2), pp2-7, Summer 1986.

Credits

Client:
Warburg Dillon Read

Architects, engineers, acousticians:
Arup Rachel Atthis, Darren Barlow, Mick Brundle, Stephen Chiles, Ruth Clifton, Steve Davis, Ian Fellingham, Martin Finch, Savvas Georgiou, John Haddon, John Hopkinson, Alistair Hughes, Rebecca Hutt, David Hymas, Rob Leslie-Carter, Gerry Loader, Iain Lyall, David Maxwell, Luke McAdam, Terry Moody, Roger Olsen, Dipesh Patel, Raj Patel, Graham Pitman, John Quick, Terry Raggett, Mark Richards, Paul Robinson, Tim Sneddon, David Spencer, Ross Taylor, Bob Venning, Paul Wellman, Clive Wilson, Julie Wood, Malcolm Wright

Main contractor:
Miletrian plc

Principal M&E sub-contractor:
Matthew Hall

Atrium canopy:
Tubeworkers(Structures) Ltd

Special glass units:
Siemens AG/Eckelt

Dealer modular ceiling / lighting and special foyer ceilings:
CCP/ Zumtobel Staff Lighting ltd

Timber joinery and toilet fitout:
Trollope Colls Elliot Ltd

Cladding smoke vents,external glass screens and revolving doors:
Pollards Firespan Ltd

Helical staircases:
Cambridge Structures Ltd

Lifts:
Leonard Lifts Ltd

Glass balustrades:
County Forge Ltd

Glass ceiling:
Haran Glass Ltd

Glass ceiling lighting system:
Zumtobel Staff Lighting Ltd

Atrium infill structures:
Watsons Steel Ltd

Moulded GRG panels and column cladding:
Riverside Mouldings Ltd

Generators:
Puma

Chillers:
McQuay (UK) Ltd

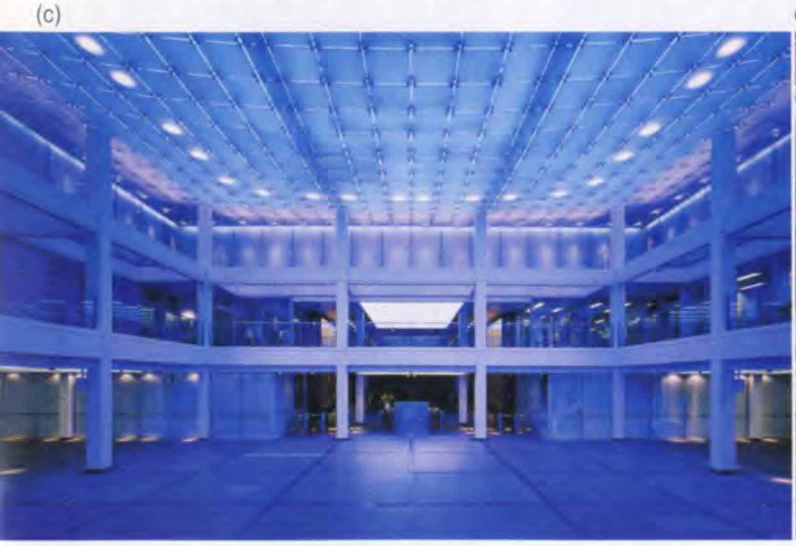
Downflow units:
Hiross Ltd

VAV boxes and diffusers:
Trox (UK) Ltd

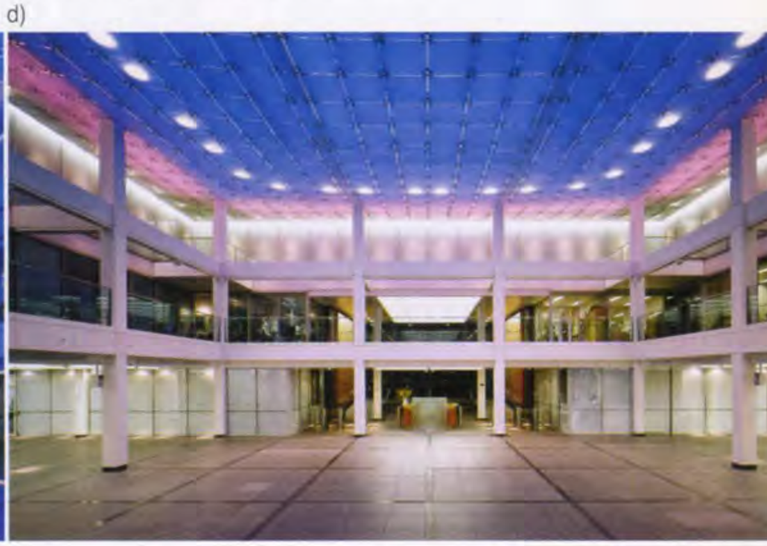
Illustrations:
1, 3, 5: Andrew Putler
2: Arup
4, 6, 7: Penny Rees
8 (a-d), 9: Nathan Willock

White and coloured fluorescent lights are controlled to provide numerous different lighting environments, four examples of which (a-d) are illustrated below.

(c)

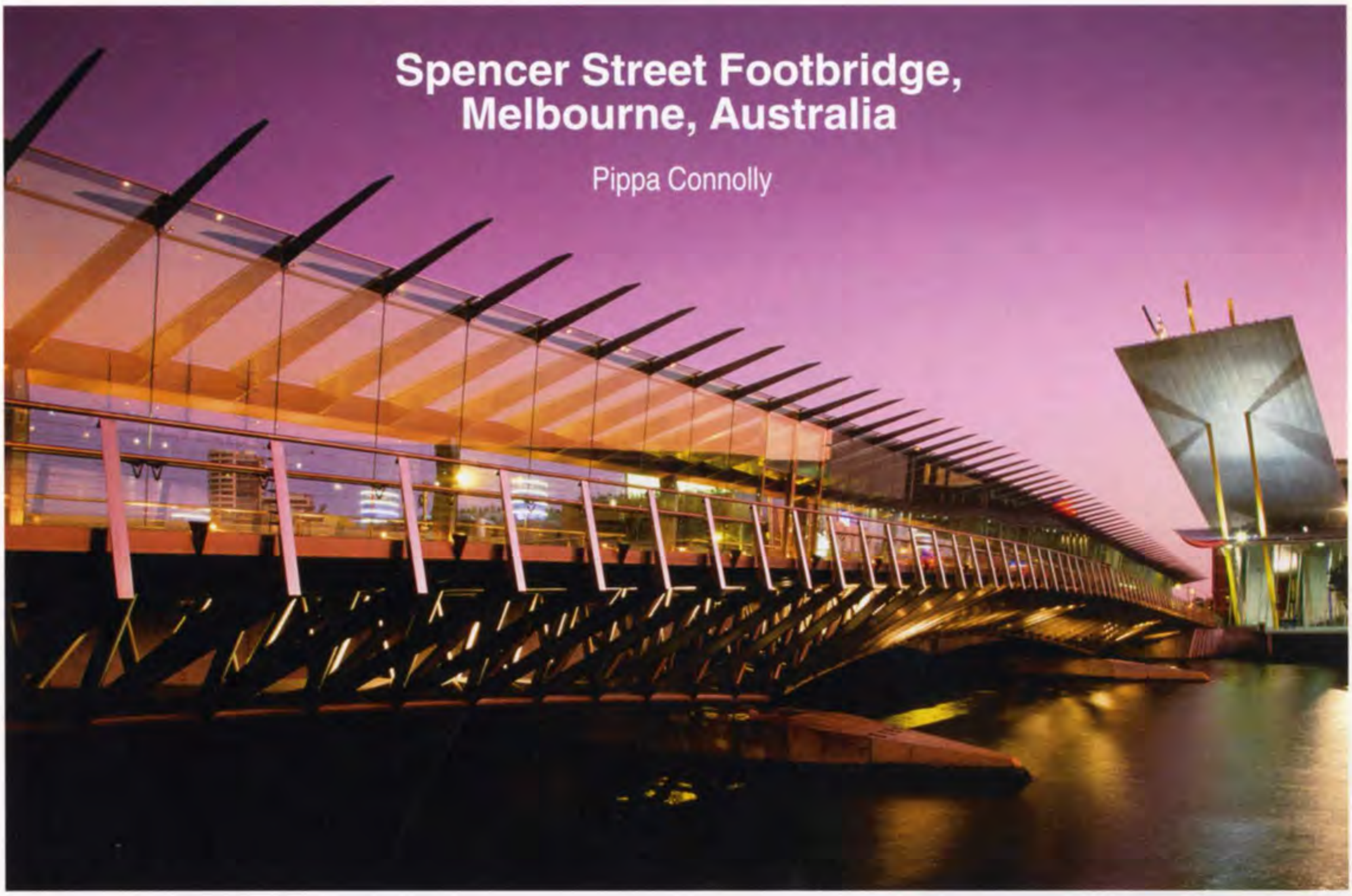


d)



Spencer Street Footbridge, Melbourne, Australia

Pippa Connolly



1.
New footbridge with Exhibition Centre in background - also an Arup project.

Introduction

In February 1997 Melbourne Exhibition Centre and Melbourne Convention Centre became one entity - the 'MECC'. To complete their integration, MECC commissioned a new covered footbridge spanning the Yarra, as well as significant enhancements to the façade and lobby of the Convention Centre (Fig. 2). In the process, a new public promenade was added to the already lively river precinct, containing the Casino, Batman Park, and the Exhibition and Convention complex.

The new footbridge adjoins the west side of the existing Spencer Street Bridge and is semi-enclosed. Its striking cantilevered glass and steel wall and roof divide the decking into two - a leeward, protected lane and an outer, exposed lane. At the northern end, a new street entrance has been forged into Melbourne Convention Centre by the addition of a large public glass-covered loggia. Internally the whole kitchen was reorganised and relocated to make room for a much larger lobby incorporating two new escalators and an entrance staircase.

Architectural design

The footbridge is both public and urban in its form and manners. Its exaggerated ribbed skeletal form (Fig 1) cuts a striking river and sky profile. As a 'found object', this could be the upturned hull of an unfinished boat, or the skeletal backbone of some ancient marine creature.

Urban design

The bridge creates an interesting urban conjunction, lying parallel with the existing Spencer Street road bridge, interlinking at the one third span points. As an adjunct structure, it traces the same profile as the road bridge, its semi-enclosed glass and steel upper structure providing shelter from the wind and rain, as part of the cross-river promenade.

The southern end spills onto Southbank Promenade under the large bladed entry canopy to the Exhibition Centre. At its northern end, the footbridge links into the Convention Centre under a large translucent green glass wall, which hovers over the Spencer Street footpath seemingly suspended in space.

Community consultation

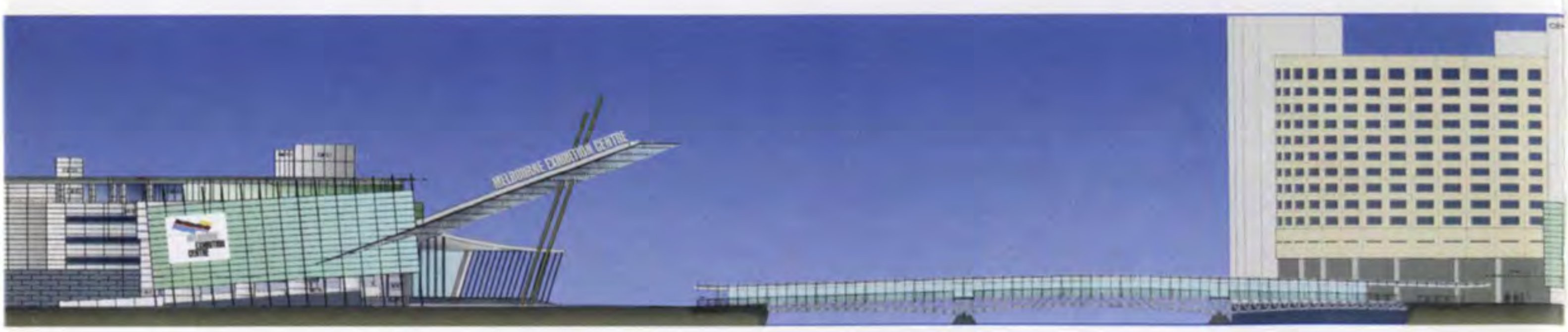
The commission for the project included writing the brief, which was undertaken in consultation with the client and the various end users, including convention and exhibition organisers. An extensive consultative process involved some 15 statutory government agencies, departments, neighbours, and authorities, as any project on the Yarra River entails a complex overlap of various authority and permit requirements.

The final configuration of the footbridge was determined by a mixture of both client and community interests. For example, it being open-ended allows for unimpeded pedestrian and bicycle access along with the north and south bank river promenades, as well as across the river (Fig 3).

Engineering design

This required Arup to think laterally - to design structures that would be both functional and economical, while contributing to and enhancing the architectural concept. A key feature of the project was the pooling of ideas from team members of all disciplines to produce an integrated structure.

2.
Montage of scheme; left: Melbourne Exhibition Centre; centre: new footbridge; right: new entrance to Convention Centre.



3:
View along open side of footbridge to Southbank.

Some of the more unusual and innovative elements were as follows:

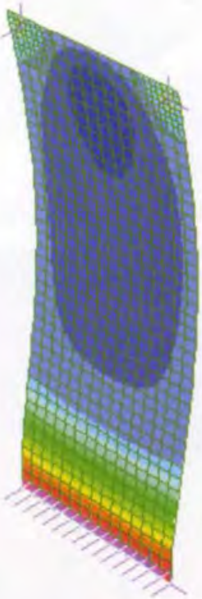
Glazing design

Arup Façade Engineering contributed to resolving one of the biggest challenges: the interface between glass and steel where all the connections are fully exposed. Traditionally structural steel and glass are fabricated to very different tolerances and are designed to move in different ways. The design of the footbridge and the loggia over the Convention Centre entrance both combine these elements.

Central to the footbridge is a large, transparent, raking glass wall, which leans a shoulder into the prevailing wind, spanning 3.8m from its base to the cantilevered roof fins. Views along the river corridor are framed by the superstructure, which sits like a sculptural curtain, hovering on the horizon line.

To achieve the clearest view of the river the glass had to appear unsupported on all its edges. This was achieved by fixing the base into the bridge deck while pinning the top at two points (Fig 4). The bearings at the top fixings not only restrain the glass, but allow it to rotate under wind loads, letting it move with the bridge deck rather than the roof.

The loggia wall glass appears as a flat sheet. Support is provided only by a series of recessed spherical fixings, hidden in the depth of the glass.



4:
Analysis image of glass stresses.

Footbridge steelwork

The structure is formed from a series of warped steel trusses, which span across the Yarra in three arches mirroring the Spencer Street bridge profile beyond. Detailed analysis was required to resolve the way the footbridge worked to ensure that it did not become unstable under any load condition.

While the base trusses for the bridge warp, the roof canopy cantilevers from the deck, and a series of profiled box sections were developed to support the canopy from the bridge. These were designed not only to handle the structural requirements, but also to house all the bridge's services. There is no applied cladding so the painted steelwork provides the final finish.

5:
Wall installation on footbridge before installation of roof glass, illustrating restraint bearings to top of glass fixed on hollow section restraint.

Much effort was put into the design of the cantilevered roof fins to ensure that they were as slim as possible. A small tube used to restrain them from buckling also doubled as the point to support the bearings picking up the top of the wall glazing (Fig 5).

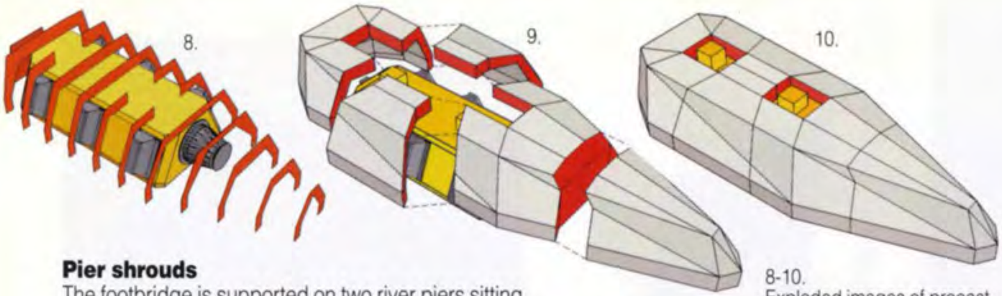
Just as much care was taken with the design of the underside of the bridge, given that this is seen by people passing along the River. This is the best place to appreciate the effect of the stainless steel props which are pinned to the bottom chord of the truss and rake upwards to form the sculpted handrail.

The installation of the bridge was a major consideration in the design, particularly as it is in Melbourne's central business district. The design enabled the main structure to be fabricated in three pieces, brought to site on trucks and installed in a day (Figs 6 & 7). To this base the raking props were added and the fins forming the canopy bolted to the top in sections. The fins themselves were designed to be cut from a standard 40mm plate, keeping wastage to a minimum.

Despite the complex geometry, the three-dimensional shop detailing, the highly accurate fabrication, and trial assemblies ensured that all the steelwork fitted together very easily with little site alteration.

6:
New bridge section sitting on existing bridge waiting to be installed.

7.
Installation under way.



Pier shrouds

The footbridge is supported on two river piers sitting on a basalt outcrop. The soil in the riverbed above the basalt is like a thick sludge, so does not give any lateral restraint to the piles forming the piers. This became a problem when designing for accidental impact load on the pier and/or bridge, there being insufficient capacity in the piles to resist this type of load without expensive foundation solutions. To reduce impact forces into the bridge, a system of concrete shrouds over fenders on the pilecaps was used. The key design criterion for the impact was a fully laden dredging barge at 10 knots (double the river speed limit) hitting the bridge and / or shroud, by hiding fenders beneath the shrouds the bridge's slender appearance was uncompromised (Figs 8-11). The 'nose' of the shroud is designed to shear off under exceptionally high impact, further protecting the bridge.

8-10.
Exploded images of precast shroud showing construction.

11.
Shroud at the precasting yard.

12.
View from inside Convention Centre looking out through enamelled glass loggia.

Loggia / Convention Centre entrance

The Convention Centre glass loggia marks a new dramatic arrival space. Here the artist James Clayden has added a second glass art wall as part of the overall urban composition of footbridge and entrance. Shimmering watermark patterns based on photographs of the rippling surface of the Yarra have been silk-screened onto the glass. The effect plays tricks with light and surface, adding visual texture on a vast scale (Fig 12).

One of the ways the loggia screen's apparent 'floating' above pedestrians in the new forecourt was achieved was by sitting the whole 12m height of glass on four raking cantilevered columns (a fifth column nearer the footbridge end was omitted to improve circulation). As a result the whole south end of the wall hangs from the existing Convention Centre stairshaft. One mullion carries a much greater load than the others as a result, but its careful engineering as a series of welded plates rather than the boxed channels the other members are makes it look the same.

Conclusion

The footbridge was opened on time and under budget at the end of 1998. Its success is obvious from the amount of pedestrian traffic that chooses to use it to cross the river rather than the road bridge. The client achieved their objective of drawing the two venues closer together and providing a more significant address to the street. The design team worked very well together from the architectural inception right through construction, resulting in an outstanding project..

Credits

Client:
Melbourne Convention and Exhibition Centre Trust

Project manager:
Office of Major Projects

Architect:
Peter Elliott P/L Architects

Structural, civil, and façade engineers:
Arup Edward Aqualina, Pippa Connolly, Joe Correnza, Andrew Henry, Peter Hoad, Peter Hrynevych, David Hunton, Paul Janssen, John Legge-Wilkinson, Brendon McNiven, Justine Mercer, Neil Paynter, John Perry, David Smith

Building services engineers:
Lincolne Scott Australia

Quantity surveyor:
Wilde and Woollard

Lighting design:
Vision Design Studio

Artist (artwork to glass):
James Clayden

Geotechnical engineer:
Golder Associates

Wind consultant:
Professor Bill Melbourne

Land surveyor:
Fisher Stewart

Building surveyor:
Gardner Group

Builder:
John Holland Construction and Engineering P/L

Steel fabricator:
Geelong Fabrication

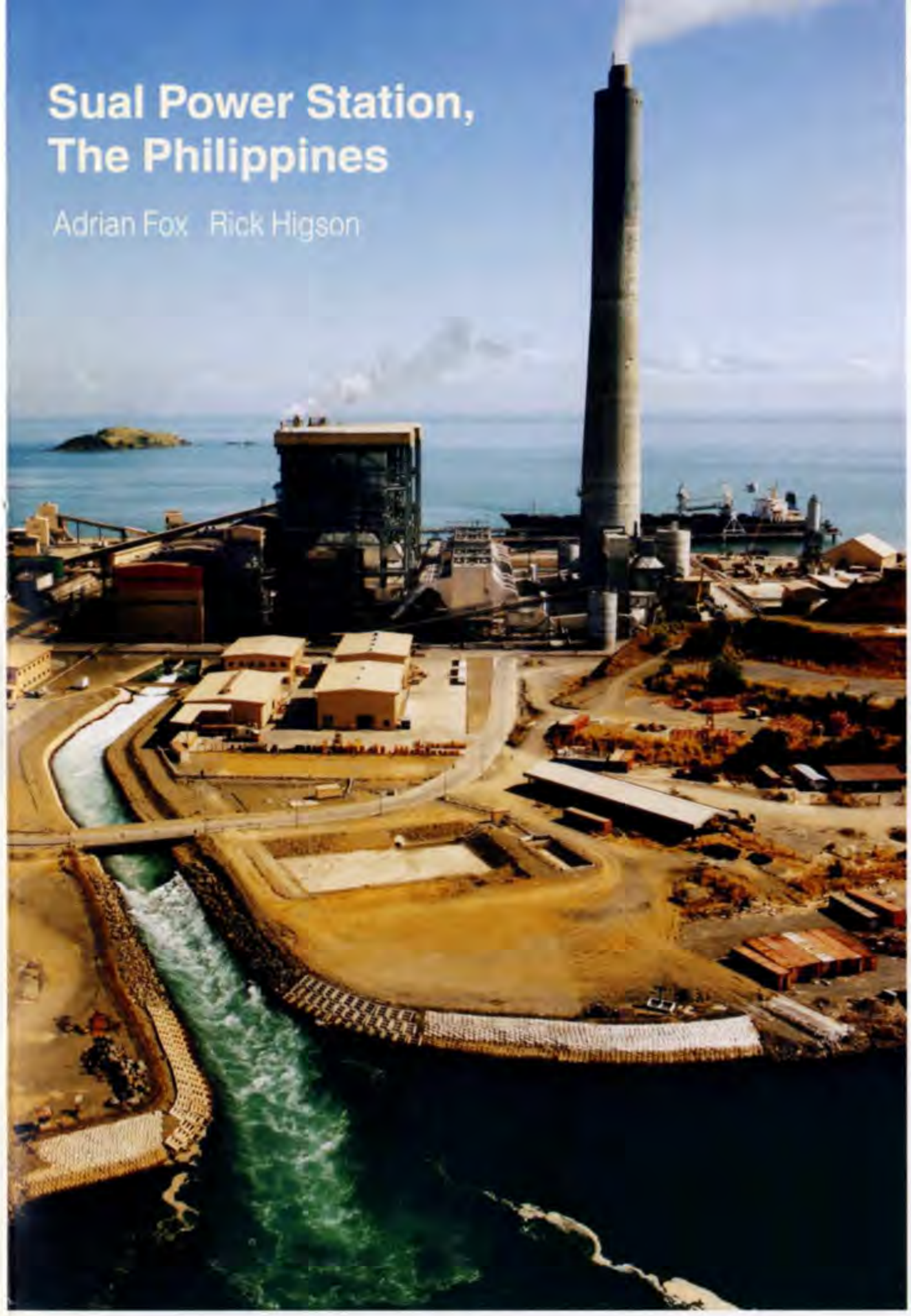
Façade installers:
Heritage Glass

Specialist glass:
DMS Glass

Illustrations:
1, 3: White and Partners
2: Vivid Communications
4-7: Arup
8-10: Tim Black, Peter Elliott P/L Architects
11: Peter Elliott P/L Architects
12: Gollings Photographs

Sual Power Station, The Philippines

Adrian Fox Rick Higson



1.
General view from south:
cooling water discharge channel in foreground

Background

Sual Power Station stands on the island of Luzon in the province of Pangasinan, about 200km north of Manila. On 24 November 1999 it completed 30-day reliability trials under full load conditions, and commenced operations. With its two 609MW generation units, it is not merely The Philippines' largest base-load, coal-fired, electricity generating plant, but also the most efficient. In addition, state-of-the-art emission control technologies, including flue gas desulphurisation, make Sual the best environmental performer of any power plant in the country, meeting the stringent requirements both of The Philippine Clean Air Act, and World Bank air quality standards.

Currently, some 43% of The Philippines' 12GW installed generating capacity is oil-fired plant, which depends on imported oil, and in many instances is nearing the end of service life. The Sual plant will help the country lessen this dependence and produce additional environmental benefits by displacing older, less efficient, and less environmentally advanced plants.

The Philippines has a tradition of power shortages, so many industrial users have installed large standby diesel generators, accepting the high cost of the electricity produced. With the growth of independent power producers (IPPs) over the past 15 years, The Philippines became an early target because of its high tariffs.

FGD: cleaner emissions

Flue gas desulphurisation (FGD) is used to remove most of the SO_2 (up to 95%) produced in coal combustion from the flue gases before they enter the chimney. The options available vary from trying to 'mop up' the SO_2 as it is produced, to processes using additional plant incorporated inline just before the chimney.

The former involve adding limestone to the bed of fluidised bed boilers or injecting limestone into the furnaces of conventional boilers and collecting the resulting sulphates in filters or precipitators. The latter processes can produce saleable by-products such as gypsum or even sulphuric acid, although the plant for acid production resembles a small chemical works and is generally not favoured. Most widely used, as at Sual, is the wet-limestone process which basically uses a slurry of limestone to absorb the SO_2 and in so doing forms gypsum which can be dried and sold for wallboards, etc.

Compared with oil or liquefied natural gas (LNG), which are high in capital cost in terms of specialised shipping, receiving plant, and storage, coal is a cost-effective solution for large base-load plants.

Current thermal efficiencies approaching 45% mean that it is also a fairly good converter of available energy.

The development of large industrial gas turbines has made gas the fuel of choice where it is available piped from source, but in The Philippines this will not happen until the Malampaya field comes on stream in 2001; piped to the south of Luzon, it will support 3000MW of power generation. Gas turbines able to produce 280MW in simple open cycle, or 400MW when coupled in a single shaft arrangement with a steam turbine operating on the waste heat from the gas turbine (CCGT), are available from all the main suppliers. Several CCGT plants are now being built in southern Luzon and will operate at thermal efficiencies approaching 60%. However, until gas comes on stream, coal can efficiently produce base-load power close to where it is consumed, and also contributes to the diversity in fuel essential in a large national grid.

The client and contract consortium partners

Following completion of Pagbilao Power Station in South Luzon, Consolidated Electric Power Asia Ltd (CEPA), a subsidiary of Hopewell Holdings in Hong Kong, bid in open competition and won the US$0.9bn BOOT (build-own-operate-transfer) contract to develop the Sual plant.

The agreement with the National Power Corporation of The Philippines (NAPCOR) was for 1000MW generating capacity, but CEPA chose to install the two 609MW units because this utilised efficient and standard format generating equipment. CEPA also recognised that, with projected growth in demand of 9% over the next decade, excess generating capacity provided the opportunity to increase revenue from the plant.

The turnkey contract to deliver the plant was awarded to a consortium of GEC Alstom (now ABB ALSTOM), responsible for supply and installation of power island electrical and mechanical equipment and the balance of plant, and Stein, responsible for the boiler works. As on previous CEPA projects, the civil works consortium partner was CEPA Slipform, their in-house construction wing who on this contract operated in The Philippines as Sual Construction Corporation (SCC).

Site preparation work commenced in 1995 with the contract declared effective in February 1996. The programme proposed 34 months for delivery of Unit 1 with Unit 2 on line three months later.

The private sector in power generation

Privatisation, and specifically the competition it engenders, represents the single most significant change in power generation over the past 10 years. Market-driven reductions in capital cost have been dramatic, and electrical power contractors and equipment supply contractors have seen tenders effectively halve in value. Plant construction costs of US$1000/kW 10 years ago have fallen to US$500/kW in today's market.

More recently, following the 1997 Asian economic crisis, projected short-term to medium-term demand for electricity in south east Asia decreased, reducing the number of commercially viable and fundable projects. As a result, competition for those that do go ahead is intense, and the effects are not only reflected in electrical power and equipment supply contract prices, but also in the way IPPs have experienced substantial reductions in market price / kWh at dispatch. 10 years ago, power purchase agreements on BOT (build-operate-transfer) projects were being entered into based on an electricity dispatch rate in the order of US7cents / kWh, whereas in today's market, rates have fallen to US4-5cents / kWh.

The challenge

The capital cost of developing power plants may have halved in response to the market, but there has been no corresponding or substantial change in the product or its delivery. On Sual, CEPA entered into a lump sum, fixed period contract for the civil works construction.

This presented significant schedule and commercial challenges. There was strong pressure to identify ways to reduce capital expenditure and improve on schedule and design, with the construction and installation costs of both the electrical / mechanical (E /M) and civil works subject to continuous review and assessment to optimise capital and operational outlay.

Though civil works only represent c12-15% of the development cost, this can significantly affect the E / M installation and hence delivery time for the plant, as well as future operational costs. In view of the fact that a 1200MW power station can generate over US$1M / day revenue, schedule, delivery times, and site productivity are fundamental to commercial success.

Arup Energy therefore discussed with CEPA the design on a value engineering basis, endeavouring to challenge accepted norms and achieve a balance between:

- optimising the quantities of materials needed in the design
- developing construction designs to improve productivity of the labour force and equipment employed
- developing simple and repetitious construction designs, which optimise the co-ordination needed between the civil and E / M work
- developing designs which respect the phased release and definition of E / M vendor information and enable staged approval and construction.

Arup Energy role

Arup had developed a long-term relationship with CEPA on Shajiao 'B' and 'C'[1] and Pagbilao power stations, and Arup Energy was initially appointed by CEPA to undertake the design and quantities control for all the civil, structural, architectural, geotechnical, and maritime engineering.
As the project progressed however, several factors resulted in Arup Energy's role increasing.

In early 1997 CEPA were bought by Southern Energy Inc, part of the Southern Company based in Atlanta, Georgia, the USA's largest electricity producer. The takeover resulted in many significant changes, particularly in management style and approach to project delivery. With the Sual project on site, Arup Energy assisted the new management on various fronts. These roles included contract procurement and construction management of elements like the coal unloading jetty; additional design packages including the ash disposal site, berthing and off-shore navigation studies; and a technical and commercial assessment of the cooling water system construction and operation. Arup Energy also provided 12 engineers and planners, fully integrated into the construction team in various hands-on roles. Duties ranged through construction planner; sub-contract managers including piling and dewatering operations; QA / QC engineers including developing the civil works construction QA / QC plan; and site design engineers involved in design liaison and temporary works design.

2.
Site plan.

Arup Energy project team

The Sual plant was the first such project completed under the Arup Energy banner and the team was established as the model for future projects.
The client was based in Hong Kong and as a result a local management presence for direct liaison was essential throughout. The project team was assembled in two stages. Initially section leaders for distinct elements were based in Hong Kong for 2-3 months to develop and agree concept design and prime quantities with the client. The complete project team was then mobilised in London around the section leaders with the opportunity for participation opened up and encouraged worldwide. Team members were drawn from Hong Kong, Nigeria, USA, and The Philippines, as well as UK groups including Civil Engineering London, Geotechnics, the Advanced Technology Group (ATG), and Arup Project Management.

3.
Coal unloading jetty.

4.
Site location map,
also showiing
local seismic features

On projects like Sual, local support and knowledge are fundamental to success, and Arup Manila made significant contributions throughout design and construction. The office was involved in designing substantial parts of the works as well as being an administration base for the design and site teams. As a result, a group of Arup Manila staff now have experience of power station design, and have been involved on other power projects elsewhere in the world.

Community relations

Many parts of rural Philippines are extremely poor with very low per capita incomes, and a project as substantial as the Sual plant has a significant impact on the region. During construction the project employed several thousand people from the local community, and long-term benefits include employment for about 500, making it the largest employer in Pangasinan province.

During both construction and operation, substantial personnel training and assistance with development of infrastructure, housing, and schooling form a fundamental aspect of the plant's development and integration with the community.

5.
Map of The Philippines
showing site location
and principal
seismic sources.

The site

The 30ha site on Luzon lies on the west side of the Lingayen Gulf. The power island is on Bangayao Point, opposite Cabalitian Island, with Pao Bay to the north and Boquioan Bay to the south. Before site preparation, the topography was a series of rounded hills 5m - 90m above mean sea level. The area is underlain by a diabase dyke complex, a medium-grained basic igneous rock often called dolerite. The dykes are steeply inclined, sheet-like bodies of igneous rock, cross cut and laid down at great depth and under conditions of extreme pressure and shear. As a result they exhibit wide variation in the degree of alteration and structure.

Design principles

The value engineering appraisal for design and construction produced a series of results which led to some significant reductions in the project's capital cost. The Arup Energy team made several breakthroughs:

- seismic design first principles philosophy
- cooling water system intake
- E / M - civil works co-ordination
- long life / loose fit
- ash disposal.

The seismic factor

The site is in a region of known moderate to high seismic activity (nominally Zone IV to the UBC[2]), and seismic risk and aseismic design were fundamental considerations throughout.

Mount Pinatubo, 100km south, erupted in June 1991 with global effects on weather and climate. It discharged 5bnm^3 of ash and pyroclastic debris (including 20 - 30 megatons of sulphur dioxide and aerosols) into the atmosphere via eruption columns 18km wide at the base and up to 30km high. The volcanic cloud circled the Earth in just three weeks and covered about 42% of the planet's surface within two months. It was the second largest eruption this century (after the 1912 Mount Katmai eruption) and managed to lower world temperatures by an average of 1°C.

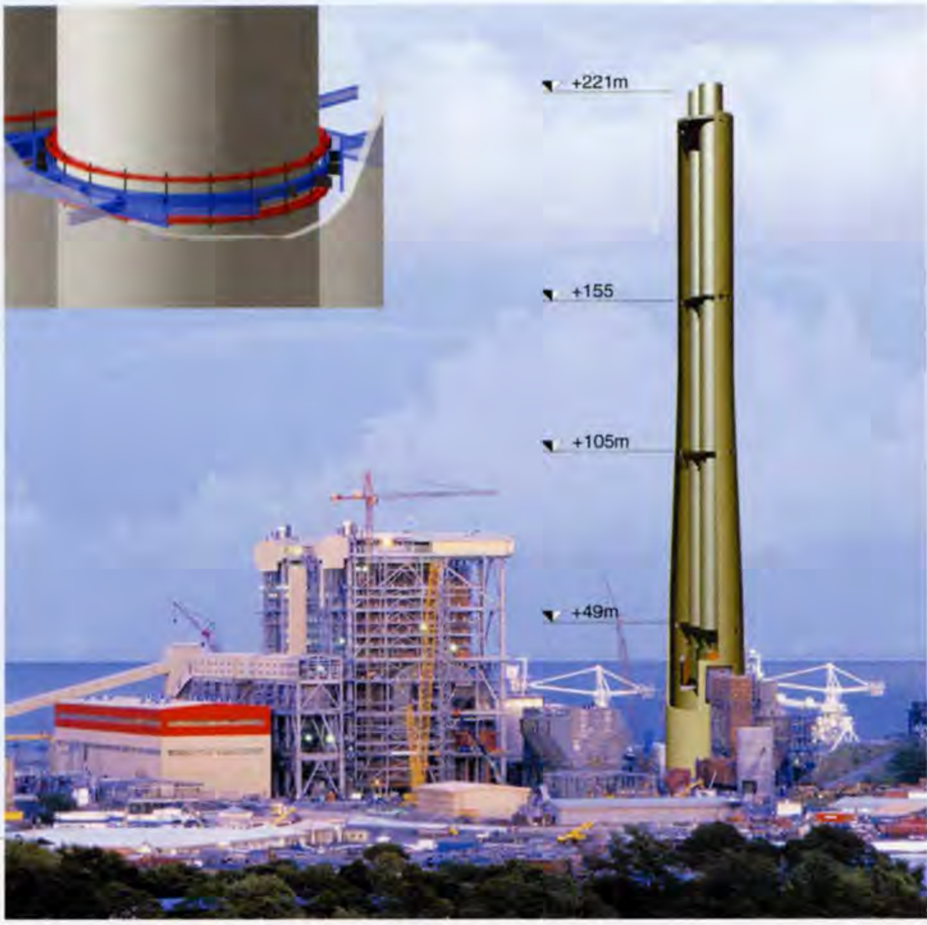
In the earliest stages, prior to agreeing project funding, Arup was commissioned to carry out a site-specific seismic hazard assessment and an initial ground investigation. The former was probabilistically based on historical records of seismicity, but did not evaluate the effects or properties of nearby fault sources. However, during the initial study, preliminary interpretation of aerial photography identified two lineaments crossing the site. Could they be active faults? Resolution of the issue was fundamental to project funding, and a two-stage strategy was proposed by Arup, with Geomatrix Consultants from California:

- Stage 1, which had to be completed to enable financial close, involved a fault rupture hazard assessment to identify whether the lineaments crossing the site were active and to evaluate the potential for surface fault rupture during the operational life of the plant.
- Stage 2 comprised a seismic source characterisation to identify potentially active faults within 25km of the site and to estimate the associated maximum earthquake magnitude and slip rate. The output of this study was then fed back into the seismic hazard assessment.

The studies showed no inherently active seismic features on the site itself, but two potentially active faults were identified nearby:

- the Hundred Islands Fault, 11km west, slip rate 0.2-1.2mm/year, fault capability magnitude M6.75
- the East Zambales Fault, 5-6km east, slip rate 0.5-2.0mm/year, fault capability magnitude M7.05.

Apart from these, another significant source is the subduction zone interface of the Manila Trench, approximately 45km from the site, capable of generating earthquake magnitudes around M7.8 - M8.9.



6.
(a): Cut-away of chimney showing support for flues. Inset (b): seismic restraint detail

The chimney flues: aseismic design

The twin steel flues in the 223m high Sual chimney are suspended from the roof slab, a design decision based on seismic loading considerations.

Fabricated from 9-12mm thick plate lined with borosilicate glass blocks for corrosion protection, the flues are restrained at two intermediate levels and at the bottom hopper (Fig 6a). They are suspended for two reasons.

Firstly, they are in tension and therefore inherently lighter than bottom-supported flues working in compression. The lower flue mass and the knock-on effect in support structures therefore results in lower seismic forces. Secondly, in a seismic event the flues move and deflect but their self-weight always tends to return them to the vertical.

The aseismic restraint detail developed for Sual comprises simple steel rods in a restraint ring around the flue circumference (Fig 6b). These allow free vertical thermal movement, but in a seismic event resist lateral movement, absorbing energy by plastic deformation in bending. Replacement of the rods if necessary after an event is simple, quick, and economical.

Aseismic design

The seismic hazard assessment studies gave the effective peak ground acceleration (pga) at the site as conservatively equivalent to Zone IV UBC (pga = 0.4g, return period of 475 years or 10% chance of being exceeded in 50 years).

Achieving economic structures requires a sound basic aseismic design philosophy, embracing strong connections, direct load paths, redundant framing, and a high degree of ductility, coupled with an iterative approach to developing robust structures whilst minimising seismic mass and load.

For many of the simple building structures the design was developed generally in accordance with UBC principles - essentially the same seismic provisions as the National Structural Code of The Philippines.

UBC is not, however, strictly applicable to many of the non-building structures and its interpretation can result in conservative and uneconomical designs. Structures like the coal unloading jetty and chimney were therefore analysed from first principles using DYNA3d software to perform non-linear time history analysis, and assess inelastic demand and the effects of soil-structure interaction.

Developing a comprehensive and consistent set of aseismic design and construction principles resulted in some significant economies in civil works construction, and for many structures their careful detailing and light-efficiency resulted in seismic loading not being the fundamental loading consideration.

On 12 December 1999, a magnitude 6.8 earth-quake with epicentre 30-40km south of Sual was recorded. This approximated to a 10-year return period event, yet the plant remained undamaged.

Cooling water recirculation

The steam that drives the two multiple stage turbines in the power island must be cooled and condensed before it is returned to the boiler. This requires much cooling water; for Sual's configuration and rating, a total of 56m^3/sec of seawater is necessary for optimum performance. In the process, the seawater is warmed by 7-9°C above its incoming, ambient temperature.

Due to its raised temperature and lower dissolved oxygen content, the water discharged from the plant can have an ecological impact on the local aquatic environment including benthos, fish farming, and mangrove habitats. The best way to mitigate this is to reduce the temperature to ambient as quickly as possible, which is also consistent with the significant operational consideration of preventing or reducing the warmed outfall water recirculating back through the seawater intake (which would reduce the thermal efficiency of the plant).

The best practice in temperate climates is to intake the coolest water possible and discharge the heated water rapidly and turbulently back to sea, so that the resulting plume quickly loses heat to the ambient, cooler water. This leads to a typical arrangement of intake heads and outfall dispersal jets at depth.

However, this was felt to be inappropriate for the tropical waters and site characteristics at Sual.

The Environmental Impact Statement (EIS) commissioned by CEPA identified the potential impact of a thermal plume and estimated its extent as well as defining the criteria by which the thermal impact would be measured.

The Philippines Department of Environment and Natural Resources (DENR) identified a maximum allowable rise above ambient temperature of 3°C beyond the mixing zone, the extent of which was to be determined by mathematical modelling.

Arup involvement

Early in the project, Arup was appointed by GECA to carry out a thermal impact study to update the EIS, taking account of contract cooling water flow rates, intake and outfall configuration and locations, and associated plume modelling.
The study identified that in the Lingayen Gulf's warm tropical waters, the most efficient way to remove heat from the warm effluent was to maximise losses to atmosphere by ensuring the warmed water lay in a stable field (stratified) at the surface of the water column. In some conditions, this layer would extend around the tip of the headland to the intake position, which could result in the warmed outfall water mixing with intake water at ambient temperature, resulting in recirculation.

Concurrently, GECA and CEPAS were developing the intake and outfall design and investigating ways construction costs could be reduced.
The initial scheme design for the cold water intake was based on current European practice - siting the intakes in deeper water offshore to eliminate the risk of warm water recirculating through the cold water system. Also, in tropical waters the top 1-3m of the water column tend to be warmer than deeper water due to direct solar gain (warming); a deep intake would avoid drawing down the surface layers. To reduce the capital cost of the civil works, however, CEPAS decided that they wished to adopt a shoreline intake with an invert level 11m below mean sea level.

With the results available from the thermal impact study, CEPAS requested Arup Energy to investigate and:

- confirm that the intended engineering solution for the cooling water system conformed to environmental Best Available Technology Not Exceeding Excessive Cost (BATNEEC).
- estimate the impact on the operating costs from accepting recirculated cooling water.
- estimate the capital cost of various civil construction options
- identify the best lifetime solution from comparison of capital and operating costs for each option.

Thermal plume modelling

Modelling the effect of a warmed water discharge into a receiving body of water is complex. The main factors affecting dispersion of waste heat are:

- evaporation from the sea surface (function of cloud cover and humidity)
- tidal currents
- wind-driven currents
- freshwater discharge (saline wedge formation in estuaries can also submerge warm water fields at depth as a result of density differences)
- residual currents (driven in the Lingayen Gulf by interchange with the South China sea).

In any season the contribution of each of these factors to cooling varies independently. A stochastic approach to the problem is required, although most graphical outputs of the extent of warm water fields appear deterministic. This involves running several seasonally and time-adjusted models and calculating the combined probabilities of each component. Analysis results for Sual indicate that the bay is poorly flushed, current effects are small, and the principal means of dispersing heat is transferral to the atmosphere through the sea surface.

This has influenced the final form of both the intake and outfall structures of the cooling water system.

The envelope of the impact of the thermal plume is indicated in Fig 7.

7. Thermal impact assessment.

Arup Energy prepared a net present value (NPV) model in spreadsheet format with the following inputs:

- turbine efficiency curve (supplied by GECA) converted to coal burn / °C temperature rise using figures supplied by the boiler manufacturer Stein
- seasonal variations in steady state temperature rise through the condensers from recirculating cooling water
- costs of coal supply
- cost estimates of construction activities associated with each scheme.

A 'most credible' analysis was presented, using appropriate interest and discount rates over the operational life of the plant, as well as ranges of key variables to determine the sensitivity of the NPV.

Arup recommended that Southern adopt a shoreline intake with a 16m deep invert level, identifying a potential overall project saving of around US$1M for this option. With this configuration, the estimated increase in coal burn cost resulting from the raised cold water intake temperatures arising from mixing was more than offset by the construction costs of the other alternatives.

8. Cooling water intake and pumphouse.

The spreadsheet was designed to be interactive and was provided with the report so that Southern could independently check the recommendations and carry out their own sensitivity analysis on long-term coal supply prices and monetary rates, etc, to satisfy themselves as to the robustness of the analysis.

Arup Energy also supported Southern in presentations to the DENR and their advisors, including modelling the mixing zone and analysing the warmed water field and its impact on the local ecology.

The Philippine authorities and their advisors accepted that the innovative design complied with both DENR and World Bank Standards for thermal impact, and accepted the necessary changes to the original EIS. Southern and GECA accepted the findings of the Arup Energy study and proceeded on the basis of Arup's recommendations.

The study and design review demonstrated that the best solution for this project with its unique plant, site, and environmental characteristics was quite different from the usual best practice adopted from European experience.

Civil and E / M works co-ordination

The civil engineering works of a coal-fired electricity generating plant represents 12-15% of the capital cost. As a result, the high value E / M equipment associated with the generating process tends to dominate the design development and form of the civil works, which are typically designed to be equipment- and system-specific.

Power plant development comprises the integration of numerous systems: from bulk material handling such as coal, cooling water and effluent; to primary power and control systems; to mechanical and electrical services installations.

Typically, the design and installation process for each system is undertaken by an independent team or sub-contractor, each with its own contract and schedule co-ordinated by the main E / M contractor. Prior to the latter finalising each sub-contract, little or no supplier information is generally available to support the design process, and as a result detail information arrives at different times, often not meeting the requirements of the civil works schedule.

This is common to many industrial processes, but particularly significant when the number of sub-contracts is substantial, as in a power plant. Arup's experience has been that the timing, integration, and co-ordination of any one of these independent design processes can significantly affect the progress and form of the civil works design, resulting in uneconomical and delayed civil works construction.

Long life and loose fit

Some fundamental structures in the plant, like the boiler, define precisely the form of the support structure. However, many elements of the E / M plant and services are more flexible, and Arup Energy perceived substantial benefits from desensitising the design by reducing the interfaces and level of co-ordination required between the civil works and the E / M installation. This required several basic decisions to be made and agreed early in the design process; these then defined guidelines for future civil works and E / M installation.

Numerous guidelines were proposed and agreed with the E / M contractor, resulting in the modular design of the process and control buildings (PCB):

- standardising the building grid, form, servicing provisions, fabric, and detail of all the ancillary plant buildings
- developing a building structure and fabric which provided for services zones and was able to accommodate service support, penetrations, and future modification
- developing a design for phased construction that reflected the release of detail vendor information and thereby minimised civils rework
- where weather canopies were acceptable in lieu of full building enclosures, omission of side cladding to give full flexibility of servicing
- top feeding services to plant, switchgear, E / M equipment, removing as far as possible the need for in-ground servicing and trenching and enabling simple, flat ground floor slab construction
- site-wide services to be run above ground rather than in trench to avoid interaction with substructures and significant drainage problems.

Setting and agreeing the principles for the civil works design and construction early in the project resulted in significant commercial benefits. Detailing of the modular buildings was standardised to minimise fabrication and erection time as much as possible. As available US EXIM - money coming from export credit agency funds - predetermined that fabricated structural steel was imported from America, details were also developed with the fabricator to minimise transportation costs, ie material volume as well as mass. From this process the 'flat pack' PCB was developed.

A few of these guidelines and principles resulted in an increase in material capital cost, but the ability for the civil works to progress ahead of finalising the E / M design resulted in significant schedule and installation benefits. The inherent flexibility of the system build also provided scope for future modification and installation during the operating life of the plant.

Considering the complexity and extent of the service's co-ordination, there were relatively few variations and interface and co-ordination problems during installation.

The ultimate in reducing co-ordination

The 45m x 15m x 14m high FGD pumps building was heavily serviced, sized to house six slurry pumps and a maintenance area. The building height was determined by the clearance required by the overhead crane when lifting a pump over the slurry header tank for maintenance. A fundamental review of the plant operation, and E / M and civil works interaction, identified that the operational and maintenance requirements were limited and that there was no fundamental reason to have a building enclosure. As there was a relatively small capital cost in upgrading the equipment to external rating, the building structure was omitted, producing significant capital saving and a more flexible and easily maintained facility.

Ash storage

The site

All the SE Asian coal-fired power stations in which Arup Energy has been involved are on coasts, with ash storage from the coal firing accommodated in near-shore reclamation areas or ash lagoons. The area around the Sual site is undeniably of outstanding natural beauty. The One Hundred Islands resort to the north, the local fish farming industry, and Sual port itself are typical of the environment found in northern Luzon and are important from both a heritage and tourism point of view. The potential impact on the coastline and any detrimental effects from the construction and operation of the facility were considered early in the design and approvals process and this led to the adoption of an inland ash storage site. Arup Energy was responsible for developing one of two sites for use by the operator.

Ash production

Fly ash, extracted from the exhaust gas by electrostatic precipitators, and bottom ash, discharged from the boiler furnace, are typically held on site in buffer storage silos close to the power island. Treated gypsum produced as a by-product of the FGD system is dealt with similarly.

Unlike in more developed regions of the world, currently there is no significant local industry in The Philippines to use these by-products of station operation to create new marketable products.*

To enable sufficient storage capacity to be available for the design life of the station, it was estimated that approximately 18Mm^3 needed to be accommodated within the selected area for both ash and gypsum.

Local conditions

The ash storage area is 3.5km from the station site in a valley with a catchment of some 1 390 000m^2, of which the ash disposal site will cover 820 000m^2. The valley's natural geology valley comprises igneous rock overlain by residual soil from 3-10m deep. The valley watercourses discharge into the Nugulong river and then into Pao Bay to the north of the main power station site. Downstream of the site, the Nugulong River supports local settlements and agriculture, and there are fish farms in the area of Pao Bay.

*Although not common practice in The Philippines, Arup Energy specified pfa in the concrete mix used to construct the concrete gravity substructure for the Malampaya Field. The structure was built in Subic Bay 200km south of Sual and used pfa from a local power station.

9.
Intérior of reverse osmosis plant, showing white seawater filters.

10 below:
Site-wide services, including electrical distribution, potable water, seawater, fire-fighting, etc.

Development fundamentals

Developing the ash storage area is a major 30-year activity. It must be both economical, and flexible and reliable in design and construction during and after the operational period.

Initially, the contaminants that might come from the ash and the extent to which these could be leached out during and after construction of the storage 'cells' were determined. Potential pathways for contaminants into surrounding ground water or watercourses were then assessed and design measures developed to mitigate and eliminate risk of contamination. Finally the design called for careful construction of the cells so that, after filling, the area will be visually indistinguishable from its surroundings.

Surface and ground water management

Arup carried out a risk analysis (using a contaminant transport modelling program: Risk-Based Corrective Action) to determine the requirement for any lining to the site. The results demonstrated that the mixing depth in the underlying bedrock had a significant influence on the concentrations of contaminant that might reach downstream extraction points. At the extreme credible bedrock permeability and ash contaminant level, the effect on downstream water quality was between borderline and acceptable, but because of the sensitivity of the site, Arup Energy recommended that a UPVC liner be used at the underside of the ash storage cells and the attenuation basin.

To assure the integrity of the ash storage site, a regime of ground and surface water monitoring downstream has been established by Arup. Benchmark tests were carried out bi-monthly prior to construction to provide data against which future water quality during operation can be compared.

11.
Ash disposal site, showing two storage cells under construction.

Ash cells

The ash storage system comprises the progressive development of 23 cells with an average area of 40 000m^2 and 15-30m deep, and a life-cycle around 12 months. At each stage, one cell will be operational and future cells under construction. Their structure comprises a containment bund, the impermeable liner, a granular base and protection layer, and a herringbone drainage network to collect runoff and leachate. An open cut-off channel is built around the perimeter to stop uncontaminated run-off entering the active cell, within which ash is progressively placed and compacted to the defined profile. When completed it is capped with clay or a membrane, and the capped cell then planted with indigenous species.

The development of the ash disposal site was a 'project-within-a-project', which demonstrated the breadth of skills available in Arup. On site, the firm performed a construction management role which also entailed design modifications to accommodate variations in ground conditions as well as to suit the sub-contractors' preferred method of working and available plant.

Conclusions

Fundamental to success in delivering projects like the Sual power plant is a clear understanding of the businesses of the client, the operator, and the E / M contractor, as well as the project specifics. This knowledge is best acquired through close, ongoing relationships, giving a comprehensive involvement in the business as a whole. Only then can the application of technical skills fully meet the project requirements and achieve breakthroughs, whether commercial, technical, or related to schedule.

On Sual, Arup Energy was initially appointed in a civil design role, but involvement in the project increased primarily as a result of comprehensive integration into Southern's construction team. The overall Arup Energy involvement eventually ran all the way from pre-engineering input to support acquisition of funding, to design, construction management and planning, through to assessment and definition of operational functions. This level of involvement enabled a number of significant contributions to be made to improving capital cost (CAPEX), co-ordination, construction delivery, and operation costs (OPEX)

Clearly, however, there is scope for enabling further improvements on this type of project. For them to be commercially viable, the intensely competitive power generation market is effectively demanding step change rather than belt-tightening in the delivery of facilities. Llimits are quickly being approached, if not already reached, to the extent that production costs for E / M capital equipment can be reduced. Breakthroughs therefore have to be made in overall delivery in terms of material quantities, installation, and scheduling.

Arup Energy believes that contributions to the step change can be derived from various sources, including further improvement in quantities, standardisation and off-site prefabrication, phasing, and co-ordination of civil and E / M works, all of which would contribute to reductions in schedule and thereby cost. Ultimately, however, the successful delivery of a project depends on the abilities of the parties involved and their integration into a co-operative team with aligned goals.

One option is even closer working relationships with the client and E / M contractor, greater knowledge of and integration into their businesses, and more comprehensive involvement and responsibility in projects from the earliest stages. Arup Energy aims to extend this further and encourage the adoption of alliancing for power projects. This fundamentally aligns the objectives of the parties and creates an environment which encourages development and breakthroughs.

References

(1) HIGSON, Rick. Shajiao C Power Station, Guangdong Province, People's Republic of China. *The Arup Journal*, *31*(2), pp22-30, 2/1996.

(2) INTERNATIONAL CONFERENCE OF BUILDING OFFICIALS. Uniform building code 1997. Volume 1. Administrative, fire- and life-safety, and field inspection provisions. Volume 2. Structural engineering design provisions. Whittier, California, ICBO, 1997.

Credits

Employer:
Pagasinan Electric Corporation (PEC)

Client:
Consolidated Electric Power Asia Ltd
(now part of the Southern Company)

EPC contractor and consortium leader:
GEC ALSTHOM Power Plants Ltd (subsequently GEC ALSTOM who became ABB ALSTOM)

GECA Participating Divisions:
Lead partner and balance of plant: PPG
(Power Plants Group)
Boiler supply and design: Stein Boilers
Coal and ash handling: Electromechanical Systems Ltd
Electrical and mechanical: CEGELEC
Turbine generator: GECA
Large Steam Turbine Division (LST)

Civil works contractor:
CEPA Slipform (operating as Sual Slipform Construction, then as Sual Construction Corporation)

Engineers and planners:
Arup Robert Addlesees, Ade Adekunle, Aleth Albano, John Alcaras, Gary Allden, Christian Allison, Andrew Allsop, Kate Aplin, Steve Armstrong, David Ash, Ricardo Barcenas, Ranjit Basu, Terry Bell, Mark Bidgood, Juliet Bird, Barbara Bissmire, Danny Bonnett, Anthony Bowden, Phil Bramhall, Darren Briggs, Rona Calvelo, Christopher Cann, Simon Cardwell, Stuart Carey, Glen Carney, Ian Carradice, Chris Carrick, Chris Carroll, Alan Chadwick, Marco Chan, Martin Chapman, Mark Chatten, Jeremy Chatwin, Alec Childs, David Clare, Joanna Clements, Justin Coe, David Collier, Clive Cooke, Ernie Cruz, Lewie Cruz, Wilma Cruz, Gavin Davies, Peter Deane, Liam Delancy, Mimmy Dino, Xiaonian Duan, David Eastland, Philip Elliott, David Ellis, Neil Evans, Adjutor Fabro, John Figg, Adrian Fox, Asim Gaba, Gaungbing Gao, Lee Gallagher, Graham Gedge, Tintin Gonzales, Andrew Grigsby, Clare Hacker, Greg Haigh, Andrew Harland, Andrew Harrison, Jos Harrison, Daire Hearne, Richard Henderson, Rick Higson, Nick Hontucan, Bill Horn, Robert Hyde, Ashraf Issak, Paul Jenner, Angus Johnson, Gearoyd Kavanagh, Andrew Keelin, Tania Lategan, Bob Lea, Richard Limentani, Brian Littlechild, Zygi Lubkowski, Chris Luker, Donald Macmillan, Ping Mandac, Jason Manning, Paul Marchant, Jo Marples, Daryl McClure, Tristan McDonnell, Grant McInnes, Sarah McKenna, Wendy McLaughlin, Andrew McNulty, Ian McRobbie, Candy Mok, Errol Morris, Pierre-Yves Mutel, Luis Navarro, Duncan Nicholson, Vincent Nyambayo, Olaolu Oladapo, Peter Oldroyd, Lincoln Oro, Daniel Osafo, Ed Palaganas, David Palmer, John Parsons, David Pascall, Prakesh Patel, Colin Pearce, Bernie Pemberton, Alf Perry, Daniel Petronis, Ted Piepenbrock, Rene Ponce, Joan Powell, Rene Quiambao, John Quinlan, Alan Ravandi, John Redding, Robin Riddall, John Roberts, John Robson, David Scarr, Tony Sheehan, Bailey Shelley, Mark Siezen, Craig Siganto, Rob Smith, Phil Stockman, Chris Stowe, Paul Summers, Brian Tang, Graeme Taylor, Cecille Teodisio, Paul Thompson, Adam Tomas, Noel Tomnay, Henry Tomsett, Che-Ming Tse, James Turner, Clon Ulrick, Jomel Uy, Terry Uy, Ben Watkins, Ian Webb, Richard Wilkinson, Michael Willford, Matthew Wilson, Colin Wright, Philip Wright

Ilustrations:
1, 3, 8-12: Stevenson Kinder & Scott
2: Penny Rees
4, 5, 7: Martin Hall
6: Hadek/Arup

12.
Central control room.

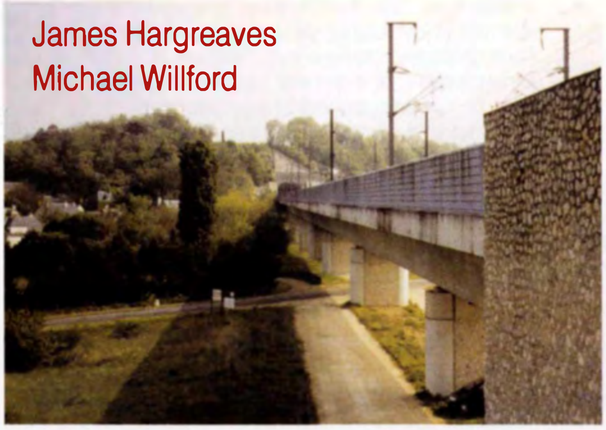
A validated acoustic prediction tool for the design of railway bridges

James Hargreaves
Michael Willford

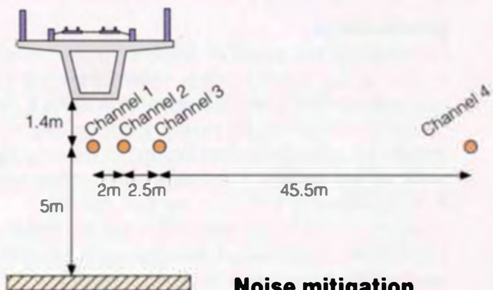
Introduction

The impact of train pass-by noise on the surrounding environment is particularly important for new railways and where high-speed lines are to operate. Elevated support structures pose a particular problem since structural resonance can often be a major source of radiated noise.

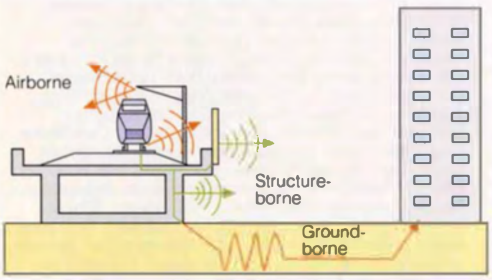
In response to a worldwide increase in planning and constructing new railways, Arup's Advanced Technology Group has developed and validated a new methodology to predict structure-borne noise radiated from elevated railway structures. This article provides some background to railway noise and vibration issues, describes the CAE (computer-aided engineering) analysis method, and demonstrates the accuracy of CAE compared with measurements from an operating viaduct. Predicted and measured 1/3rd octave band A-weighted structure-borne noise levels and total noise levels are compared and shown to be in good agreement.



2. Typical viaduct used for noise data measurement.



3.
Microphone positions.



1.
Categories of noise and vibration.

Background

It is usual nowadays to appraise the acoustic performance of a new railway bridge design as early as possible, so that noise mitigation requirements can be addressed and where necessary implemented in the design. Consideration of noise and vibration falls into three main categories (Fig 1):

• Airborne noise

This is propagated directly from the vibration of the wheels and rails and to a lesser extent at the pantograph. The vibration arises from the movement of wheel treads (which have surface roughness) over railheads (which also have roughness and vertical undulation), and to a lesser extent from the deflections of the rail spanning between the sleepers as the axle passes over.

Vibration grows with increasing train speed, so airborne noise becomes particularly important for high-speed trains travelling at over 300kph.

The noise from this area is of course exacerbated by resonances in the wheels and rails, typically occurring at frequencies of 500Hz and above. Appropriately-positioned trackside barriers can provide acoustic protection to adjacent buildings by shielding them from the direct sound waves from the wheels and track.

• Structure-borne noise

The vibrational forces generated at the wheel/rail interface pass into the bridge deck through the rail pad, sleeper, and ballast. The panels of deck structures are flexible at acoustic frequencies and typically have hundreds of modes of vibration even below 300Hz.

The presence of these modes means that noise can be radiated from the deck sidewalls and soffits, and also from trackside barriers attached to the deck. When control of airborne noise demands a high barrier, this large radiating surface - effective in reducing airborne noise - radiates more structure-borne noise.

• Ground-borne noise and vibration

Railway-induced vibration propagates through the ground and into adjacent buildings through their foundations. Once into building columns, the vibration is amplified in the vibrational modes of the walls and floors, whence it is then radiated as noise into the building interior and / or directly felt by occupants.

Noise mitigation

Mitigation is needed if predicted or actual noise levels exceed legislative or contractual requirements of developing a new railway. Criteria are often expressed as sound exposure limits over specified time periods (eg day / evening / night or 24 hours) in the vicinity of the railway such that disturbance to people living and working nearby is minimised.

When mitigation is required, the designer has to develop a system that meets not just noise and vibration targets but also cost, durability, and other critical performance criteria associated with railways such as RAMS (Reliability, Accessibility, Maintainability, and Safety).

Several measures have been developed to reduce structure-borne noise, such as (in order of increasing effectiveness and cost) soft rail pads, sleeper soffit mats, and ballast mats. Sometimes a degree of noise mitigation can be designed into the bridge structure itself. Where target noise criteria are exceeded, a choice must be made between alternative solutions, and compromise between noise reduction and cost is often necessary. It is difficult to assess this without a reliable initial estimate of the structure-borne noise levels.

Operational mitigations, such as regular track grinding and polishing, are also essential to maintain good noise performance, particularly for airborne noise.

Regular wheel truing is also necessary, as wheel roughness is also an important vibrational force generator, particularly on power-cars where cast-iron tread brakes are used, causing uneven wear and leading to high levels of air-borne noise and higher forcing levels for structure-borne noise.

Train pass-by measurements

To provide structure-borne noise data to correlate with the model, measurements were made adjacent to a typical viaduct (Fig 2) carrying a high-speed rail system. Four microphones were used, positioned mainly to separate as far as possible direct airborne noise from structure-borne noise (Fig 3). Three were put close to the underside of the deck box-girder, since the noise here would be primarily structure-borne, these points being entirely within the 'shadow zone' of direct acoustic sources emanating from the wheel / rail interface. The fourth microphone was placed in the field of airborne and structure-borne noise.

Measurements here are important because they provide data at locations around the viaduct representative of where people might live or work. Fig 4 shows a typical recording of a 10-second train pass-by event at 270kph.

CAE analysis

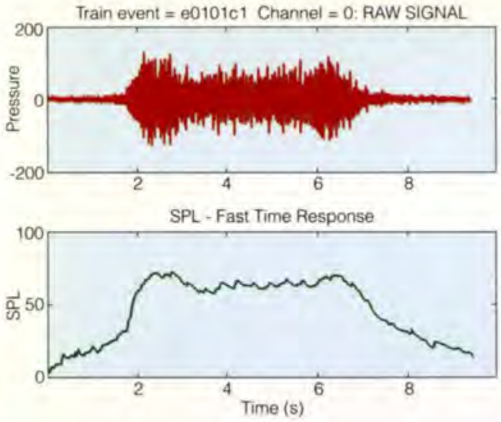
For a known noise problem, several methodologies are available to evaluate how potential ameliorative measures perform. A simple model can often be used to assess a series of design proposals to reduce the noise, without the need to predict absolute levels. The problem is more difficult at the design stage when absolute noise levels have to be predicted for an unbuilt structure and for a railway not yet in operation. Though, if a reliable absolute estimate can be made, bridge designers can make better-informed choices between alternative structural designs and on the need for and degree of mitigation required.

A detailed modelling approach, well-researched input parameters, and an understanding of the sensitivity of the results to the inevitable uncertainties in the input are required to make such a reliable estimate.

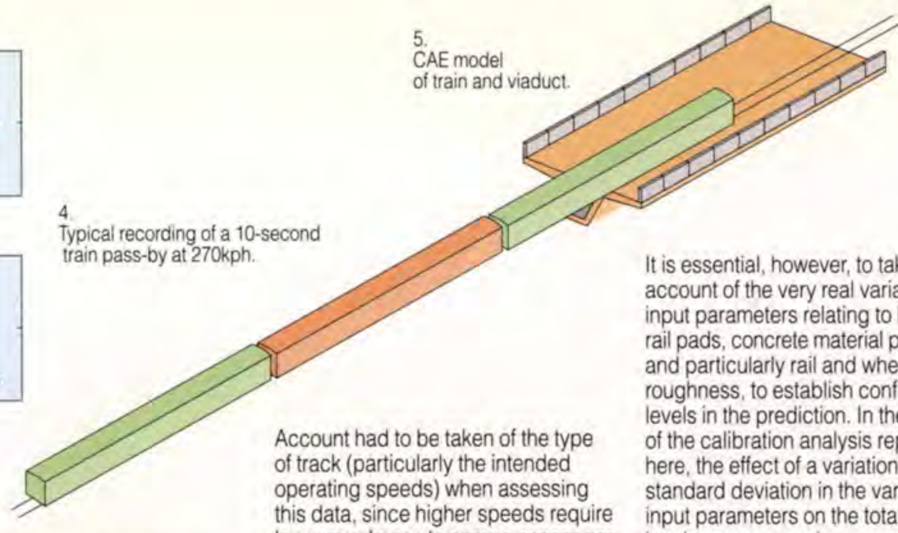
The method developed combines time domain finite element (FE) and frequency domain boundary element (BE) methods. It is computationally intensive, but it can now be solved with a combination of modern computing hardware and software and efficient modelling practice.

The development of a suitable procedure required consideration of the following:

- proper simulation of the generation of vibration from wheel / rail contact roughness
- design of meshes valid to predict structural waves at all frequencies up to 300Hz
- developing a suitable level of simplification of an entire viaduct structure
- incorporation of suitable damping models.



4.
Typical recording of a 10-second train pass-by at 270kph.



5.
CAE model of train and viaduct.

It is unnecessary and computationally unfeasible to represent an entire multi-span viaduct, maybe over 1km long, in this type of analysis. Ways to simplify the system are required so that the methodology is efficient and produces a problem size possible to run on a modern computer.

The first step in simplification is to model only one span with a detailed 3D model. A further simplification is for only a single deck, typically lying between two expansion joints, to be represented. Using this approach, the model (Fig 5) consists of:

- a detailed 3D model of a single span (c45m long)
- a detailed model of the train (three cars) and trackwork on this span
- a beam element representation of the remaining spans of the bridge.

Adequate representation of the (small wavelength) structural modes present in the deck cantilever, sidewalls, and soffit at frequencies up to 300Hz was the main criterion for establishing the FE mesh detail. The rail and sleepers were expected to have many resonances below 300Hz, but these would not typically involve sectional deformation or warping, so these components are modelled using beam elements able to represent the axial, bending, and shear waves. The rail pads are modelled with springs and dampers connecting all translational and rotational degrees-of-freedom (dof) on adjacent rail and sleeper nodes. The important dofs for the railpad model are vertical translation and rotation about the horizontal axes. The ballast is modelled by an array of springs and dampers connecting the sleepers to the deck. The mass of the ballast is smeared into the deck. Properties for the ballast, etc, were obtained from industry research. The bridge bearings supporting the span on the piers are also represented with spring-damper type elements, and account was taken of whether the bearing was fixed, free, or guided.

The fundamental mechanism generating vibration and thence noise is the small amplitude rise and fall of the train wheels to follow track and wheel roughness profiles. The accelerations produced by this kinematic requirement result in oscillating inertia forces from each wheel acting at its moving contact point with the rail.

Track and wheel roughness form the primary forcing inputs to the analysis; the values input to the analysis are based on measured roughness spectra from existing rails and wheels.

Although frequency domain solutions have been adopted in the past, working from measured roughness spectra, the method developed here is performed in the time domain (using LS-DYNA). In this case an explicit representative roughness profile is modelled for each rail and wheel, generated from the spectra. Once these profiles have been defined, they are used as part of a line (Hertzian) contact model, in which the rail roughness profile is explicitly represented.

Lines of beam elements representing the rail bending, shear, and torsional stiffness support the contact. The roughness profile of the wheel is also explicitly modelled in a special contact surface definition at the ends of the wheel model. This type of model will automatically calculate the inertia forces as the wheel / rail contact patch is projected across the railhead over the roughness.

As the contact patch moves on its trajectory, it suffers displacements due to the roughness profiles and also from vibrational displacements within the track and deck structure. To implement this simulation in LS-DYNA, the train needs to be initialised on a stretch of track adjacent to the viaduct by applying gravity and then an initial velocity to the train. An explicit time domain method has advantages over the frequency domain method in that the effect of moving wheel position is automatically represented (including inter-sleeper rail deflection) and non-linear contact and suspension properties can be modelled. It is also computationally more effective as higher and higher frequencies are required. Since DYNA calculates vibration at very small time steps, it contains in any case high frequency information automatically (subject to the accuracy imposed by the mesh density).

The rail and wheel roughness parameters are the key inputs to the simulation, and also the most variable. An extensive search of the literature and other sources of measured roughness spectra was made.

Account had to be taken of the type of track (particularly the intended operating speeds) when assessing this data, since higher speeds require lower roughness to ensure passenger comfort and reduce wear.

A 'mean' spectrum for high-speed track was then derived from the relevant measurements over the wavelength range of interest (in this case 150mm to 2500mm).

The velocities on the viaduct radiating surface were then calculated using LS-DYNA, and transformed into a 'vibrating panel' boundary condition in the SYSNOISE boundary element code used to make the noise prediction. SYSNOISE performs a frequency-domain calculation in one or more interior and / or exterior domain. In this case a single exterior domain, namely the air outside the viaduct structure, is modelled and a free-field noise prediction made. Sound pressure can be calculated at any number of field points introduced in to the domain of interest.

Predicted and measured noise

Fig 6 shows comparisons between measured and predicted noise as A-weighted decibels in the 1/3rd octave bands, individual bands being shown so that similarities in frequency coloration can be observed. The total level, equal to the sum of all frequency bands, is also shown. This measure is important, as it would typically be used to make comparisons against the noise limit, and would represent the structure-borne noise heard by an observer at the side of the railway.

The typical difference in total noise between CAE model and field test is only around 3-5dBA, giving high confidence in the use of this method as a design tool for bridge engineers seeking to establish absolute noise levels from a new viaduct design.

It is essential, however, to take account of the very real variance in input parameters relating to ballast, rail pads, concrete material properties, and particularly rail and wheel roughness, to establish confidence levels in the prediction. In the case of the calibration analysis reported here, the effect of a variation of one standard deviation in the various key input parameters on the total noise has been assessed.

It was found that rail roughness was, by far, the parameter with the greatest variation and influence on the noise. The accuracy of this methodology can be controlled to an extent by the roughness inputs. As might be expected, there was little variation in concrete modulus and density and also little effect on the total radiated noise. Railpad stiffness variation, within one standard deviation, also had a small effect on noise: it really requires a step-change in railpad design to produce any significant change in noise.

Conclusion

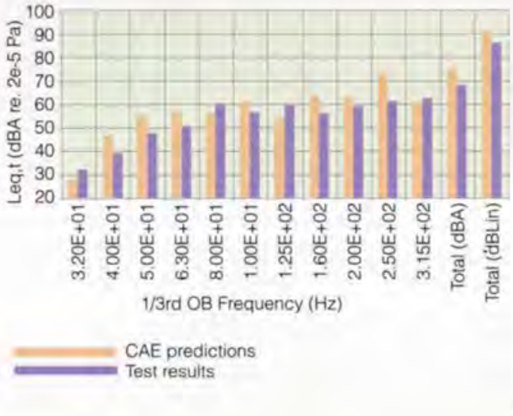
A validated means of predicting structure-borne noise from railway viaducts has been established with known accuracy, creating a design tool that can be deployed during the concept phase so that informed design choices can be made before the bridge drawings are effectively frozen. This design tool can also be applied during the detailed phase or even deck construction, but here choices become limited to ameliorative counter-measures on the track system.

This tool has significant commercial benefits, including the expectation of reduced capital cost for mitigation measures through reduction of assessment tolerances, and reduced design and programme risk.

Credits

Engineer:
Arup Andrew Cunningham, Richard Greer, James Hargreaves, NGK Meng, Richard Sturt, James Talbot, Michael Willford

Illustrations:
1, 3-6: Jennifer Gunn
2: Arup



6.
Comparison between measured and predicted noise.

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