THE ARUP JOURNAL

3/1999

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Vol 34 No 3
3/1999

Published by
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Front cover:
Seismic-resisting structure of the CEC building, Taipei, Taiwan (pp18-20)
(Illustration: Arup USA)

Back cover:
Allegheny Riverfront Park, Pittsburgh (pp22-23)
(Photo: Edward Massery)

Manchester is Britain's third largest airport after Heathrow and Gatwick, and plans to increase passenger throughput to 30M pa by 2005. A key part of this programme has been the development of Terminal 1 into two elements: the refurbished and extended Terminal 1 and the largely new-build Terminal 3. A multi-disciplinary Arup team provided a full engineering design service for both, including geotechnical, civil, traffic, structural, mechanical, public health, electrical, airfield systems, acoustics, fire, baggage handling, airbridges, and project management.

In the new South Africa, many small emerging firms of building contractors urgently need help to develop their business and management skills so that they can operate successfully and legitimately. The South African Department of Public Works asked Arup's South African practice to research, develop, and subsequently implement a programme of assistance. This is establishing for emerging contractors a regional structure of information resources, access to work opportunities, training, and support, with performance monitoring and evaluation throughout.

A team from Arup's Industrial Division has looked afresh at the subject of industrialised housing, and how factory processes can successfully deliver the right product at the right price to a wide variety of clients. This article briefly reviews the history of industrialised housing in the UK and the factors that have led to past failures, sets out some fundamental ground rules relating to product and price, and describes the proposed factory process to supply the successful solution.

This new 13-storey, 60m tall office tower is the corporate headquarters building of the Continental Engineering Corporation in Taipei, Taiwan. As well as providing a landmark structure for the client, the key challenge facing the design team, including Arup's Los Angeles office as structural engineers, was to develop an exposed seismic-resisting system throughout the building's height that would not interfere with the interior column-free space. This challenge was shown to have been successfully met when on 21 September the building survived the 7.6 magnitude earthquake unscathed.

Arup resources in New York, Berlin, Edinburgh, and London collaborated on the structural, electrical, and building information technology engineering design of this 14m tall electronic scrolling-text column sculpture designed by the US artist Jenny Holzer for the Northern Entrance Hall of the new Reichstag in Berlin.

Working with landscape architects Michael Van Valkenburgh Associates and the artist Ann Hamilton, Arup USA undertook the civil, structural, and acoustic engineering for this project to open up for public use a long, narrow site between Pittsburgh's Golden Triangle business district and the Allegheny River. The Riverfront Park comprises a cantilevered river level walk plus a ramp to bring pedestrians down from the street to river level.

Manchester Airport Terminal 1 redevelopment

Garry Banks Stephen Burrows Alasdair Gibson Richard Hattan
Paul Holder Charles MacDonald David Twiss

1 top:
The Manchester Airport redevelopment in context: British Airways Terminal 3 + apron + taxiway in front (centre foreground), and Terminal 1 Central (behind), with refurbished Pier B to the left

Introduction

In May 1993 Manchester Airport plc, a company drawn from the 10 councils of Greater Manchester, issued a 10-year development strategy outlining its aims in passenger capacity and handling through to the new millennium. Currently serving more than 16M passengers a year, Manchester is Britain's third largest airport after Heathrow and Gatwick, and ranked 20th in the world for international traffic. Its planned growth will increase passenger throughput to 30M passengers pa by 2005.

To extend and refurbish Terminal 1 was a key element in achieving this, and early in 1995 Ove Arup & Partners Manchester were invited to join a design team headed by Nicholas Grimshaw & Partners (NGP) to submit a proposal to MA plc for the project's complete architectural and engineering design services, with Turner Townsend as quantity surveyors. NGP duly became lead designer in May 1995, and shortly afterwards Bovis Lehrer McGovern were appointed construction managers and Bovis Construction Ltd planning supervisor. The project team was completed when MA plc identified their own project management and briefing team members during July 1995.

In April 1996 all team members moved into a purpose-built office by the site. As the project picked up momentum, the full team, including MA plc, numbered over 150 construction professionals, including 50+ from Arup. All construction work had to be done alongside 100% operation of the airport's existing facilities. This posed many major challenges, and was effectively executed through using a phased access and logistics plan developed by all parties and combining the most appropriate engineering solutions with the needs of the construction sequence, costs, and the airport's operational needs.

Arup service

Arup provided a full building engineering design service:

- geotechnical
- civil
- traffic
- structural
- mechanical
- public health
- electrical
- airfield systems (including aircraft docking guidance, airfield ground lighting and apron / taxiway signage)
- acoustics (Arup Acoustics)
- fire (Arup Fire)
- communications (Arup Communications)
- baggage handling (Arup Manufacturing)
- airbridges (Arup Manufacturing)
- project management (Arup Project Management).

Project outline

The two major elements were Terminal 1 Central (T1C), and Terminal 1 East. The former primarily involved refurbishing and extending the existing building to increase substantially the available retail space, create a much larger and more attractive tax and duty-free facility and - most importantly! - improve the passengers' experience. This was to be achieved by opening up spaces, improving circulation, and providing maximum contact with the outside to overcome the existing facility's claustrophobic feel.

Terminal 1 East - 'British Airways Manchester Airport' or Terminal 3 (T3) as it is now known - was predominantly new-build and created a new 50 000m² terminal solely used and occupied by BA - their largest operation outside London. Associated with this was the creation of a fully serviced apron and taxiway to serve it.

With a total project value of £91.5M, the split was approximately £40M to T1C and £51.5M to T3.

Work started in December 1995 with the first demolition packages clearing several buildings, including hangars, to make way for building T3. In April 1997 the newly extended International Lounge and tax and duty-free facilities in T1C were opened to the public. Various further phased completions were achieved through to final completion in July 1998. T3 handled its first operational domestic and international flights in June 1998, following the official opening by the Deputy Prime Minister, John Prescott.

Aprons and associated systems

Design considerations

Aprons are where aircraft park whilst they are prepared for flight and their cargo (passengers and luggage) unloaded and reloaded. Clearly, aprons must be connected to the airport taxiway system, and themselves have taxiways to get aircraft to their stands or passenger gates. The complexity of the overall arrangement depends upon the numbers of stands on the apron and connections to the main taxiway system, the operational flexibility required for ground movement of aircraft, and the proximity of the apron to taxiways and runways.

Safety is of paramount importance, and the highly proscriptive requirements of CAP 168[1] must be complied with in the design. Whatever the class of aircraft, and whatever the operating conditions under which they are required to move, there must be no possibility of either aircraft conflict/collision or pilot confusion. The Safety Regulation Group (SRG) of the Civil Aviation Authority (CAA) monitors compliance.

T3's apron provides six new stands for Code E aircraft (the largest class in international aviation standards), with three access/egress points to and from the main taxiway ('Juliet') serving Manchester's first runway.

The airport operates continuously, 24 hours a day, 365 days a year, regardless of weather conditions (apart from the strongest winds).

Low visibility does not prevent aircraft landing and taking off, so there are numerous ground movements of aircraft arriving and departing. Often, in low visibility conditions, the airport will attract extra flights from neighbouring aerodromes not licensed to operate in such conditions.

All these aircraft have to move under their own power and guidance either to their designated stands, or to the runway for take-off - and in complete safety. The airfield at Manchester is designed and operated to the highest standards defined in CAP168; these impact upon safety clearances, surface movement guidance systems, and overall operational procedures, particularly restrictions on vehicles other than aircraft within the movement area.

Typical operations around a parked aircraft include:

- passengers boarding by airbridge or mobile steps, after walking or being bused to aircraft
- baggage loading to the aircraft on articulated carts and then into the hold by conveyor
- aircraft cleaning and reloading with consumables for the flight (food, water, duty-free goods, etc.)
- aircraft servicing, including refuelling and provision of ground-generated power to avoid the aircraft having to run its auxiliary generator - greatly reducing background noise.

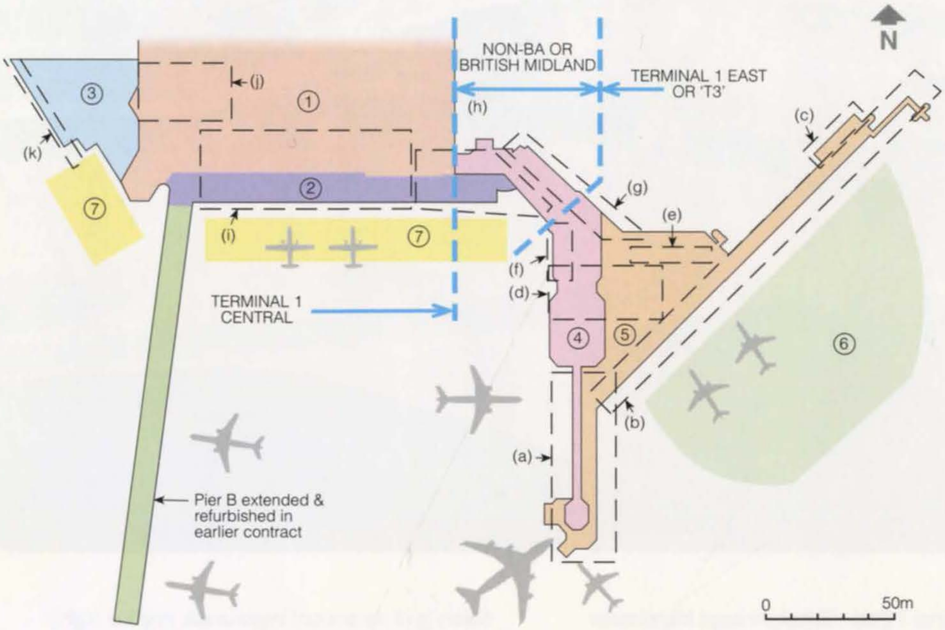
Finally, in readiness for departure, a tug manoeuvres into position in front of the aircraft, connects to its front gear with a draw-bar, and pushes it back into a position on the apron taxiway from whence it moves off under its own power.

Many vehicular movements associated with aircraft servicing and airfield inspections and maintenance happen continuously on a roadway system integrated into the apron and taxiway system (movement area). Facilities include a head-of-stand road running in front of the stands to allow direct access between aircraft. Formerly this was typically combined with a rear-of-stand roadway for circulatory traffic movement, but as this is no longer acceptable, the head-of-stand road is a two-way carriageway taking all traffic.

The six new stands on the T3 apron (Fig 5) serve aircraft ranging from the Boeing 747-400 to smaller regional jets like Boeing 737s, etc, served by airbridges, hydrant refuelling, fixed electrical ground power, and docking guidance systems (DGS) for pilots to bring aircraft onto stand without the aid of a marshall. Additionally, a fire hydrant main was installed at the head of stand, feeding hydrants between each stand.

Designing an aircraft stand involves intricate consideration of specific aircraft characteristics, each requiring optimum location of facilities. Typically these include:

- safety clearance to adjacent stands
- fuelling points (within 4m of fuel hydrant in parked position, and ideally away from wheel track zones)
- location and height of DGS (clearly visible to the pilot from far enough away for him to correct any misalignment, and for it to differentiate sufficiently between aircraft types to ensure the plane halts at correct stop line)
- location of aircraft doors
- sufficient space for catering vehicles and tug manoeuvring.



Dates	Key	Main areas
Start - January 1996 First handover - April 1997 Complete - July 1998	①	Area of existing International Terminal 1: whole area refurbished in discrete phases whilst maintaining complete operation of terminal.
Start - January 1996 Complete - June 1997	②	Southern front extension 100m x 20m creating fully glazed façade overlooking apron. Façade of area 1 completely removed.
Start - January 1996 Complete - May 1997	③	Stand 21 extension, creating large new passenger lounge and tax/duty free facility.
Start - January 1996 Complete - June 1998	④	Existing domestic terminal - Pier A, whole area refurbished.
Start - January 1996 Complete - June 1998	⑤	New international terminal construction: obvious interface with existing domestic terminal, including 100% hold baggage screening baggage handling system.
Start - January 1996 Complete - June 1998	⑥	New apron, taxiway, and aircraft stands: all fully serviced.
Start - November 1995 First handover - February 1996 Complete - June 1998	⑦	Apron and other civil works associated with stand realignment/relocation and building extension.

Sub areas

(a) - Flexible pier, serving both domestic and international flights: five stands including two new airbridges.

(b) - International pier, serving six new stands including four new airbridges.

(c) - Energy centre: sub-station, AGL control room, generator, boiler plant, water and oil storage.

(d) - New linked domestic/international passenger lounge leading to immigration/customs.

(e) - New check-in and arrivals hall - international: 26 new check-in desks.

(f) - Relocated and refurbished check-in desks - domestic.

(g) - New retail/cafe outlets.

(h) - Dedicated British Midland facility including 12 check-in desks, baggage handling system, dedicated stand, and passenger lounges.

(i) - New and refurbished areas providing retail, café, and restaurant facilities.

(j) - Relocated and refurbished immigration/security/passport control.

(k) - New passenger corridor to relocated and refurbished stand 21 nose-loader (passenger bridge).

2. Site plan.

Pavement design

The ground conditions were known to be both poor and variable - soft clays and silts with sand lenses, and a high water table. Given the pavement design's critical dependence on geotechnical assumptions, the plate-bearing strength was estimated for the pavement thickness design, which was later verified and adjusted as needed. A performance specification was included in the tender for the contractor to test subgrade compaction and carry out a defined sequence of work dependent on the test results.

The apron pavement was in traditional pavement quality concrete (PQC), designed to PSA guidelines[2], for a design life of 40 years. Predictions of annual departures of various aircraft from the apron together with growth predictions were supplied by the airport's Facilities Planning department and these were equated to a number of passes of a 'design aircraft'. A thickness of 410mm PQC on a 200mm lean concrete base was established.

The T3 Taxiway Link was similarly in PQC, but was designed to the then new BAA Guide, produced in response to the need for strategically important airfield pavements to be designed to a higher level of service and for current and predicted heavy loadings. A higher loading was designed for, due to its linking function to access the existing runway and the future runway 2, giving a 485mm thickness of PQC on a 150mm lean concrete base.

The basic layout of the stands and taxiway centrelines were defined by the Facilities Planning department to suit expected usage of the new terminal and to interface with the runway 2 design. The overall geometry was designed to achieve CAP168 safety clearances to predicted movements of the design aircraft (the MD11).

Apron lighting and signage

Aviation Ground Lighting (AGL) is defined by ICAO (International Civil Aviation Organisation) Annex 14 as 'any light specifically provided as an aid to air navigation, other than light displayed on an aircraft', the UK interpretation of which is published by the Civil Aviation Authority (CAA) in CAP 168[1] and CAP 655[3]. Further reference documents are the Aerodrome Design Manual parts 4 and 5, Visual Aids and Electrical Systems[4, 5].

The surface movement guidance system comprises airfield ground lighting (AGL) - brilliant coloured lights inset into the pavement indicating the taxiway centreline and edge - and internally-illuminated, large, taxiway guidance signs, (offset from the taxiway edge to give operational clearance to overhanging wings and engines) giving directional guidance to pilots. Additionally, stop bars and runway guard lights (or 'wig-wags' - pairs of yellow flashing lights at each end of a stop bar) are provided to warn pilots of aircraft and vehicle drivers that they are approaching or are about to enter an active runway, thus preventing inadvertent incursions to a protected zone.

Baggage handling

Andy King Adrian de Vooght

Background

Being able to transport passenger baggage reliably and quickly from check-in desk to sort point, and then to the correct aircraft, is fundamental to any airport's business. Security screening is also essential for international flights.

The baggage handling for T3 included two systems - one for British Airways valued at £8M (including screening equipment) and one for British Midlands for £400 000 (without screening equipment).

In the months following the first 'baggage handling meeting' on 26 June 1995, the terminal design was completed and a performance specification defining the client's requirements prepared.

Competitive tenders for designing and installing the systems were obtained in May 1996, and the contract for both was awarded in December 1996 to Teleflex Systems Ltd (mechanical systems and lead contractor) with MacDonald Humfrey (Automation) Ltd as controls subcontractor. The British Midland system was operational in September 1997 and the main T3 system in May 1998.

Key design parameters: T3 system

- a maximum 'busy hour' capacity of1600 bags/hr, allowing for a peak of1900 bags/hr for Stage 1 (up to 40 check-in desks)
- six minutes' maximum transit time from check-in to baggage hall
- 100% hold baggage screening (HBS) lines for normal and oversize bags between check-in, transfer, and sortation
- Two new manual racetrack carousels (for airside baggage sortation).

Key design parameters: British Midland system:

- a maximum 'busy hour' capacity of 450 bags/hr, allowing for a peak of 540 bags/hr using 12 check-in desks
- OOG bags use the same conveyor system as in-gauge bags.

3. International baggage reclaim in T3.

T3 system

The contractor's solution comprised two slat carousels, known as 'diplodocus' conveyors. Bags from check-in desks, domestic, and international transfers are injected onto the main diplo, but before reaching it are separated (side by side and front to back), and toppled to ensure correct orientation and single unit allocation onto the diplo. They are then pushed off for security screening before returning to the diplo for sortation. The second diplo is used to store and transport bags for second stage security screening.

The control system divides the diplo carousels into segments, each 2030mm long, onto which a single bag is injected. All bags in the system are given a unique source code for identification and tracking purposes when they reach the diplo. Once bags are on the diplo they are continually tracked, with their source identification, security screening status and destination attached to the segment number they were injected onto. This information can be displayed on the Management Information Control System graphic screen. The CCTV that monitors the entire system is also controlled via icons on the graphics screen, making the system extremely user-friendly.

The security screening, a multi-stage process using x-ray and computer tomography, clears around 90% of baggage automatically. Experienced operators view the remaining 10% as images on a remote workstation. All cleared bags are then scanned by an array of laser bar code readers and routed to the correct destination read from the bag tag. Uncleared bags are sent on dedicated conveyors to a location in the main sortation hall where further security action is taken.

4 left: Baggage handling, T3.

The stop bars consist of red AGL positioned at 3m centres transversely across the taxiways. All this is designed and operated as a single system with all components acting integrally under the control of a ground traffic controller to give totally clear and safe guidance to pilots in all visibility conditions.

The system operates such that only the route to be followed by the pilot is illuminated, its visibility ensured by positioning the lights at 7.5m centres along the centreline on interleaved circuits so that, should one circuit fail, a recognisable pattern of lighting is retained. The complexity of the taxiway geometry, with numerous intersection points and possible routes for aircraft to follow, led to many single routes which the ground traffic controller might wish to select and illuminate for a pilot. This route selection needed careful consideration in terms of circuitry and control, to ensure the requirements of CAP 168 were met and the optimum system selected for flexibility and cost.

A traditional control system would have required separate circuits for each section of the route, both straight and curved, and then the total doubled to enable interleaving of the circuits. Each circuit would then be controlled by a constant current regulator (CCR) with the overall control system operating the switching of the CCRs.

On the T3 apron and taxiway link, over 120 circuits with 120 CCRs would have been required by a traditional system.

Careful consideration was given to this during the design period. Such a traditional system was felt to be both inflexible and comparatively expensive in terms of circuit installation and the quantity of CCRs needed. Various alternative systems were reviewed and an addressable control system called BRITE2 selected; this considerably reduces the number of circuits and CCRs and also provides maximum flexibility for the future should the routes on the apron need to be reconfigured.

Each luminaire is fitted with an addressable unit that enables the routing to be controlled from the operating system, so that creating individual routes becomes a software programming exercise.

Apron equipment and interfaces

Visual docking guidance systems were installed at each stand, allowing pilots to park aircraft at the stands without the need for marshalling.

At each stand each aircraft type has a different stopping position - very important as they are set to ensure correct clearances are achieved around the parked aircraft from fixed obstructions and other manoeuvring aircraft and also to ensure that passenger loading bridges, refuelling hydrants, and aircraft ground power can all be readily connected to a parked aircraft. Parking outside the relatively strict parking tolerances leads to boarding and disembarkation delays.

5. New stands and apron.

6 & 7. Before and after southern front addition to T1C.

Azimuth guidance for nose in stands (AGNIS) and parallax aircraft parking aid (PAPA) have been used at T3. The former provides centreline alignment; the latter stopping distance information. Both units can either be fixed to the terminal building or on independent supports, but the correct sightlines for the pilot from the aircraft cab are essential in determining the most suitable location. At Manchester the most accurate way of determining the AGNIS and PAPA unit height was found to be simply visual - pulling the largest and smallest aircraft onto the stands and sitting in the cabs.

Apron lighting is from 25m high mast columns with a varying number of 1kW floods on each. Each stand has a vertical illuminance of 20lux at a height of 2m above the apron. Apron lighting is provided for use at night by aircraft and aircraft maintenance.

Ground power units (GPUs) were installed to each stand to supply power to the aircraft while they were docked. GPUs were sized at 60kVA, 90kVA, and 180KVA, depending on the aircraft using the stand, and were freestanding or underslung to the underside of the airbridge. All GPUs operate at 200v, 400Hz.

Baggage reconciliation equipment was installed at each stand, comprising a PC and scanner, connected to the baggage handling system, to confirm that any particular item of baggage is appropriate for the aircraft being loaded.

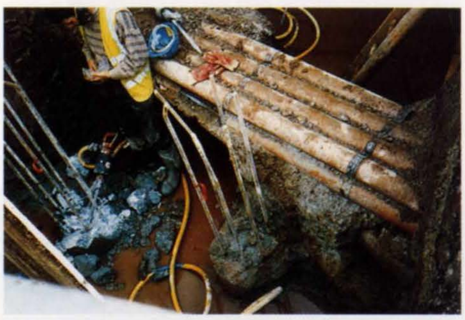
10.
T1C duty and tax-free area.

Structures

Terminal 1 Central

The extensions to Stand 21 and the Southern Front are both independent buildings with no physical connection to the existing structures. They are reinforced concrete frames with in situ slabs on piled foundations, and steel roofs. A movement joint of 40mm was formed between the old and new structures to allow for frame sway.

Foundations were generally flight-augered piles with a small number of tripod bored piles required where headroom under the existing building was restricted. The main problems during foundation design concerned existing below-ground services.



8.
Proximity of piles to existing services.

The southern front extension was being constructed over what had been the old head of stand road - (Figs 6- 7) - and was expected to be a challenge. With poor record information of the below-ground services a series of trial pits were hand-excavated to give a more accurate picture of the service types and locations. Early in the design it had been intended to divert the services to outside the building line, but as the survey results came back it became clear that this would not be possible due to cost and time constraints. Amongst them were the airport's main radar cable and a main fibre optic communications cable which to divert could have taken up to eight months and cost c£1M. It was decided that structural gymnastics could avoid these diversions, with detailed risk analyses to ensure that, during construction, operatives or the airport's operations were not exposed to unacceptable risks.

By removing a cantilever section of the existing first floor accommodation, it was possible to squeeze a line of piles in between the existing foundations and the vast array of services: the radar and fibre optic communication cables in addition to the high and low voltage cables and drains. Modifications had to be made to several existing cable chambers and drainage manholes to construct the pile caps and ground beams. Because of the closeness of piles to existing live services, (Fig 8) a tolerance of ±50mm was specified for the installation of the piles and strict working procedures implemented.

9 left:
The airport had to maintain full service throughout the works.

Within the existing terminal building the architect wanted to create a column-free vista from the passport control desk to the new tax and duty-free shop and other retail units (Fig 10). To do this several existing columns supporting the roof over the original departures lounge had to be removed. This was achieved by constructing 'goal post' arrangements over the column to be removed. Existing columns were strengthened by casting a reinforced concrete beam around the existing steel beams or by forming a lattice girder using existing steel roof beams as the top and bottom boom members, with the addition of new diagonal web members to create the cross bar. The capacity of the existing piles was reviewed and, following a detailed building movement study, in some cases deemed adequate without the need for any reinforcement.

Terminal 3

This four-storey structure also comprised a reinforced concrete frame with in situ slabs on piled foundations, plus a flat steel roof within which upstand features included raised plantrooms and the circular clerestory feature over the BA lounge. The steel frame for this was formed from a circular truss fabricated like a truncated cone and then topped with a 'bicycle wheel' roof. Arup's efforts on this element were rewarded when the architect raised the ceiling to expose more of the structure than originally planned (Fig 12). Around the main structure, many steel-framed satellite stand lift and stair towers were constructed, linked to the main building with high-level passenger bridges.

Acoustic design

Paul Malpas Nick Boulter

Background

Ask most people about airports and acoustics and they will assume this relates to the sound insulation of the external building façade. Whilst this is a critical factor, there are many other facets to acoustic design that make for a successful airport. Manchester involved Arup Acoustics in:

- architectural acoustic design (building envelope, internal finishes, internal privacy)
- mechanical services noise control
- electro-acoustic and system design of the voice alarm (VA)
- input to specialist designs, eg baggage handling and loading bridges.

Envelope

Noise levels on an airport terminal façade vary enormously through the day. The fairly constant noise associated with stationary aircraft is overlaid by short-term peaks from landings and take-offs (typically 10dB more than landings). Surprisingly, though, the highest façade noise levels occur during ground movements. An aircraft pulling onto a stand can generate in excess of 100dBA, with smaller ones sometimes pushing it even higher, partly because their engines arrive closer to the façade.

Noise levels affecting the envelope at Manchester were calculated from measurements around the existing terminals and from tests at other Arup Acoustics' airport projects.

The sound insulation requirements of the external façade are primarily dependent on the use of the internal space. Unfortunately there is a dearth of published information on the acceptability (or otherwise) of short-term peaks in noise associated with individual aircraft movements. One thing is clear, though: in most public areas of an airport, aircraft noise is expected - especially where there is a clear view of those generating the noise. Experience from other airports shows that maximum intrusive noise levels of up to 70dB(A) are acceptable in public areas such as lounges, concourses etc. At these levels, the incoming noise is noticeable over the general 'hubbub' but not so high as to inhibit normal speech and PA/VA announcements.

The assessment showed a glazing configuration achieving Rw 38 to be sufficient for most circulation spaces. This is at the edge of what is achievable with 'thermal' double glazing units (ie, not specialist constructions).

Careful planning was used to limit the number of more sensitive spaces (eg VIP lounges, meeting rooms, etc) directly exposed to high sound levels. This way the need for constructions offering much higher standards of sound insulation was able to be avoided.

Internal acoustics

The internal acoustics of the public spaces have an important effect on the general comfort and, more importantly, the intelligibility of the VA system. As this is used as an emergency evacuation tool, announcements have to be of a certain standard.

The combined responsibility for room acoustics and VA enabled a carefully optimised design to be developed, balancing architectural needs with intelligibility requirements. Checking during commissioning has shown that the target room acoustic conditions have been achieved in all the public spaces.

VA design

Airport design involves a significant number of specialist building services. VA systems are not specific to airports like, say, airbridges or baggage handling, but their merits closely match the design challenge.

Principal benefit

Major terminals are often complex and unfamiliar to even regular users. The public are compelled to remain in the building (eg to catch the flight) and would find it easy to ignore conventional alarm sounders as false or inapplicable. Passenger flow and space planning requirements add complexities to the evacuation planning, separating passengers across the national boundary and avoiding routes to the apron. Unlike a railway station, aeroplanes keep landing even if there is an incident in the terminal!

Speech intelligibility

The key parameter in VA design is speech intelligibility, which indicates how effectively the system is capable of communicating clear, potentially life-saving information. Setting an appropriate intelligibility standard has occupied the VA industry in the UK for some time, particularly in recent years. One objective measure is speech transmission index (STI). Recently updated standards recommend an intelligibility of STI 0.5, but advise that lower standards may be applicable if agreed by concerned parties. From extensive research for LUL in London and for MTRC in Hong Kong, Arup Acoustics can present a confident case for STI 0.45 in certain spaces, such as ticket halls, concourses, etc.(Fig 11).

The technical issues relating to achieving a standard of speech intelligibility are derived from both room acoustics and loudspeaker layouts. In practice, achievability is determined more by what architectural measures can be provided to control acoustic response than by the efficiency of the loudspeaker layouts, but these two elements are inextricably linked. This is illustrated in the two examples shown below. In each case, two loud-speaker schemes are considered and each scheme is assessed in terms of the maximum compatible reverberation time (RT). Remembering that a lower RT in a space requires more acoustic absorption, the pairing of loudspeaker schemes with RT offers options to the design team that are true solutions.

There are further electro-acoustic issues to consider, but this approach is valid in deriving a scheme.

International Departures Lounge

Loudspeaker scheme	*Maximum RT (speech frequencies)*
Ceiling speakers overhead	1.5s
Column speakers at 2.5m mount height	1.6s

BA Check-in Hall

Loudspeaker scheme	*Maximum RT (speech frequencies)*
Ceiling speakers overhead	1.6s
Column speakers at 2.5m mount height	2.0s

11. Completed T1 BA check-in hall showing Penton MC-402 column loudspeakers on the row of monitor housings (arrows indicate typical positions.)

12. New international lounge, T3.

One side of the new terminal abutted the existing Domestic Terminal. The old domestic Pier (A) was extended as part of the works by 'wrapping' the new building around its perimeter. This created quite a challenge in setting out, as the long thin pier with an octagonal bulb end was already an extension to the original terminal. It had been 'best fitted' into the corner of the building. Points of reference were either covered, or out on the apron.

At the interface between new and existing buildings, newly-installed baggage handling equipment extended from the new concrete building into the existing composite steel-framed one. The baggage handling specialist contractor provided loading information for the new belts and Arup checked the existing long-span steel beams from which the belts were to be suspended. After the installation was complete it became clear that the loading criteria supplied by the contractor did not include ▶

Fire safety engineering

Andrew Gardiner

The main design challenges were the restrictions imposed by the Building Regulations, which designated the Airport as a 'place of assembly'. Approved Document B of the Regulations imposed limits on compartment sizes, means of escape, and travel distances, but these were too restrictive on NGP's design. To move the design forward, a fire engineering approach was needed to satisfy the Regulations' functional requirements.

Due to the configuration of retail and concourse areas, one suggested way forward was to make an analogy with shopping centre design, but this proved inappropriate because of the Airport's complexity and particular functions:

- large undivided spaces and good way finding
- security considerations
- populations unfamiliar with their surroundings
- need to limit operational disruption
- baggage handling and airside services.

Arup Fire made a start by addressing the boundaries and positions of fire compartments, which was done in relation to the Airport's functionality rather than by restricting the design to prescribed areas. A fire load and fire spread analysis then showed that this met the Regulations' requirements.

With the compartments established, means of escape were then developed with NGP. A place of safety was designated as:

- a projected stair or corridor leading to outside
- an adjacent fire compartment
- a final exit.

For security reasons, the need to prevent escape from landside to airside or vice versa was also addressed.

In many public concourse areas, travel distances to exits were slightly greater than prescribed in codes. Also, data from the client on the existing terminal was considered when assessing evacuation times from different areas.

As a consequence, smoke control systems were installed together with sprinklers in high fire load areas like retail units. The smoke control system was designed to keep smoke above people's heads during evacuation. It also prevented smoke spread via open doors to adjacent compartments.

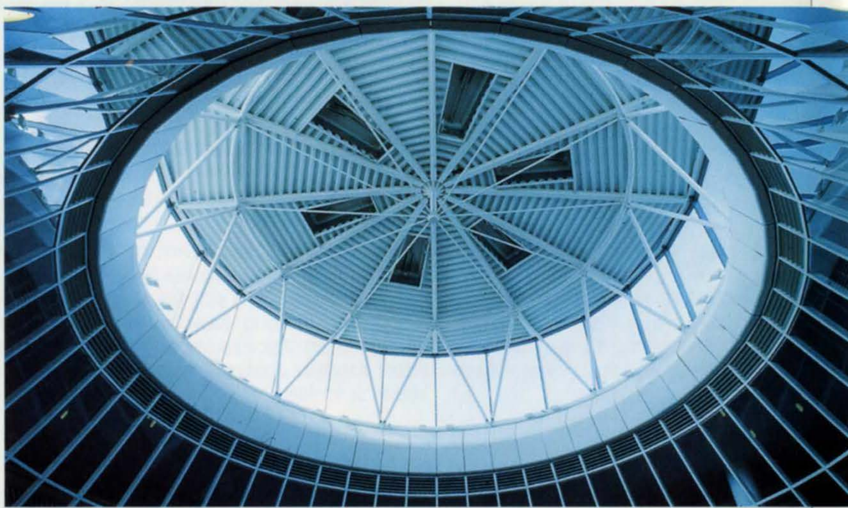
This compensated for extended travel distances and allowed ease of evacuation.

In retail areas, fast response sprinklers were used to limit fire size (2.5MW heat output) and rate of smoke production.

The client asked for the sprinklers to extend a further 3m outside the retail units to cover potential spillover of product displays from shops.

In the concourse areas it was shown that the low fire load in discrete areas resulted in a low risk of fire spread, so no sprinklers were required. The design fire in the concourse was 1.5MW heat output - analogous to a fire involving two trolleys laden with rucksacks.

From the performance specifications developed by Arup Fire, Arup in Manchester and NGP developed the scheme and detailed design. One of the main challenges was to use the existing fire safety systems, eg smoke vents, (Fig 13) wherever possible and yet make this compatible with the overall strategy for the Airport, and was particularly relevant during refurbishment of T1C, which had to remain in continuous operation.



13.
Clerestory frame above new international lounge, T3, containing smoke ventilators.

▶ any dynamic effects from the 'pusher' arms which controlled the direction of flow of bags on the baggage handling system A vibration problem was identified on the floor above each time these arms were operated

Arup Acoustics were able to measure vibration patterns, before a recommendation was made to the baggage handling specialist as to where remedial action might most effectively overcome the problem.

Airbridges

Parallel with the baggage handling system design, the requirements for passenger loading were developed. The existing terminal building employed several methods - busing to remote stands, simple external mobile staircases, nose-loaders and apron drive airbridges. In June 1996 a performance specification was issued for the design, installation and commissioning of six apron drive airbridges, four of them with 'underslung' ground power equipment to enable cabling and equipment to be incorporated.

The airbridges were designed to meet the specific aircraft requirements of each stand and because aircraft types, stopping positions, and centreline geometry were different for each stand, an individual solution for each airbridge was necessary. Critical reference documents include CAP 168 (which does not specifically refer to airbridges but sets out requirements for clearances between obstructions and moving aircraft) and AHM 922[6], which refers specifically to both nose-loaders and apron drives.

The six airbridges installed can serve a wide range of aircraft (up to Boeing 747-400 and B777s) and cost approximately £250 000 each.

As well as the new airbridges, Arup also provided a performance specification for removal, relocation, and complete refurbishment of an existing nose-loader. Because the nose-loader was being installed in a different location, its geometric relationship with the centreline and stop positions changed, making it necessary to increase its extension and retraction capability to ensure it could still serve the briefed aircraft.

Building services

Background

With a total mechanical, electrical, and public health engineering contract value of c£20M, the design, procurement ,and installation of these works was seen as key to success. As with the main project, the MEP design was split into two distinct parts. T1C had a high content of complex alterations to the existing installations, ensuring that the operational areas of the airport were unaffected by the refurbishment and extension. A detailed phasing and logistics plan (PAL) was developed, identifying small construction zones in the 'live' terminal where work would be completed before moving on to the next zone. This meant the design had to include several interim stages before implementation of the final design. Life safety systems were a critical part of this process, maintaining 100% protection throughout the course of the works for both passengers in 'live' areas and the operatives in the work zones.

Because the 'as installed' information for the existing terminal had not been maintained, Arup had to survey all areas before starting the detailed design, in many instances the results necessitated the PAL document being amended to take account of uncharted critical services which could not be removed or relocated.

Although T3 was mainly new build, there were interfaces with existing operational areas which had to be accommodated in a phased design - though to a lesser extent than T1C.

14.
Co-ordinated mechanical and electrical services in international departure pier, T3.

Electrical services

The existing 6.6kV high voltage ring main was diverted and extended to create new substations to serve the new and refurbished areas of the development. The system, though a private network, is operated and maintained by Norweb. New standby generators were installed to provide supply security to essential services. Typically these were essential lighting, life safety, security, communications, and systems associated with airfield operations. An existing generator was also removed from site, refurbished, and reinstalled as part of the works.

Lighting and emergency lighting was generally provided by compact fluorescent luminaires with feature uplighting to roof lights and curved roof profiles using custom-built enclosures, as well as back lighting to glazed walls and 'sail' fabric ceilings in public lounges and circulation spaces.

Other systems designed by Arup were:

- analogue addressable fire detection and voice alarm systems working on the double knock principle with a comprehensive cause-and-effect operation including plant shut downs and interfaces with door access, security and baggage handling systems
- door access control systems
- automatic pass validation
- public address
- CCTV and security systems
- complete airport communications system including all equipment room design, Cat 5 backbone cabling, voice and data and structured wiring outlets needed to drive the specialist airport systems such as flight information display screens (each driven by a local PC connected to the structured wiring system), common user terminal equipment, and baggage reconciliation.

Mechanical services

The primary heating source is via medium temperature hot water (MTHW) at 121° and 99°C (F&R) for air heating and hot water generation purposes, with low temperature hot water (LTHW) non-storage calorifiers, strategically located to serve fan coils and miscellaneous heat emitters. As part of redevelopment, the existing heating systems were reconfigured to provide a new dual fuel boiler installation (8MW), allowing capacity (c1.1MW) to be given back to the existing plant to cover the expansion works within the existing T1C development.

Most of the cooling is by a new air-cooled screw (R134a), chiller installations of 1.2MW (T1C) and 2.5MW (T3).

Secondary chilled water is generated locally by various low loss header circuit arrangements to serve fan coil units, etc.

Three-port control was adopted for compatibility reasons, since there were interfaces between new and existing heating and cooling systems. All main pumped circuits incorporate inverter motor control for client/operational flexibility.

The ventilation systems provided comprise either full fresh air or recirculation air systems and served public and staff areas, with capacities of approximately 220m³/s (T3) and 160m³/s (T1C). Systems serving large public concourse areas incorporate CO_2 and two-speed fan control for energy-saving reasons, since occupancy patterns can vary so greatly. All main air systems also incorporate inverter motor control for client/operational flexibility.

Staff and fit-out areas are in general served by airside control four-pipe fan coil units, though some waterside control types are used to suit particular load/installation arrangements. Systems were also zoned to suit layout and operational requirement.

Wherever possible, fresh air intakes have been located at high level, facing away from apron areas due to kerosene fumes, though all main air-handling systems incorporate carbon as well as panel and bag filtration.

The existing Honeywell Excel BMS control system was extended to serve the new development for the control and monitoring of all mechanical services installations together with sprinkler, lighting, and miscellaneous electrical/transportation systems via approximately 2500 (T1C) and 5000 (T3) control points.

Other systems designed by Arup were:

- smoke ventilation systems for smoke clearance and control purposes
- sprinkler and fire protection systems including hose reel and dry risers for fire authority use
- domestic hot and cold water services including a new 185m³ below-ground storage reservoir
- modification and extension of the existing gas distribution network
- new 120m³ bulk fuel oil storage facility for alternative heating
- BMS automatic control.

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(4) INTERNATIONAL CIVIL AVIATION ORGANISATION. Aerodrome Design Manual: part 4 - Visual aids. ICAO, 1983.

(5) INTERNATIONAL CIVIL AVIATION ORGANISATION. Aerodrome Design Manual: part 5 - Electrical systems. ICAO, 1983.

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Credits

Client:
Manchester Airport plc

Lead consultant:
Nicholas Grimshaw & Partners

Consulting engineer
(civil, geotechnical, structural, M&E, public health, fire, acoustics, communications, baggage handling, project management):
Arup
Garry Banks, Helen Bladen, Graham Bolton, Nick Boulter, Mark Boyle, Leslie Bradley, Graham Britton, Mike Buckingham, Steve Burrows, Michelle Cahill, Eddie Carmichael, Bob Carville, Sheperd Chipidu, Jane Collins, Colin Curtis, Adrian De Vooght, Paul Dean, Steve Doran, Mark Elsegood, Paul Entwistle, Michael Foster, Andrew Gardiner, Alasdair Gibson, Mark Green, Richard Hattan, Paul Holder, Rick Houghton, David Hughes, Sharon Hulme, Ian Humphreys, Jo Iddon, Lee Jordan, Peter Keogh, Andy King, Robert Leslie-Carter, Charles MacDonald, Paul Malpas, Mani Mannivan, Viv McCullough, Ian McKenzie, Paul Murphy, Darren Paine, Chris Pynn, Simon Roberts, Harry Saradjian, Graham Scull, Manan Shah, Tony Sumner, Craig Taylor, Pat Thorpe, David Twiss, John Waite, Trevor Wheatley, Garry White, Brian Wilcox

Cost consultant:
Turner & Townsend

Landscape architect:
Terence O'Rourke & Associates

Specialist lighting:
Jonathan Spiers & Associates

Construction manager:
Bovis Lehrer McGovern

Planning supervisor:
Bovis Construction (North)

Client's briefing team:
RW Gregory (consulting engineers)
Gleeds (cost consultants / project management)
Manchester City Architects

Illustrations:
1, 9, 10, 15: Incorporated Production Solutions
2: Jennifer Gunn
3-5, 7, 11-14: Peter Mackinven
6, 8: Ove Arup & Partners

15.
Terminal 3 façade.

Sakhasonke

South Africa's Emerging Contractor Development Programme

Des Correia Helen Crosby Cliff McMillan Nick Weinmann

Introduction

In November 1996 Arup was approached to help the South African Department of Public Works (DPW) define and implement its Emerging Contractor Development Programme (ECDP). The first phase was to define the scope and action required. This entailed researching departmental policy and procedures, identifying problems experienced by emerging contractors, and examining other initiatives already under way.
In mid-1997 the firm was appointed to implement its proposals.

The objective is to develop the business and management skills of technically competent emerging contractors in a real project environment so as to facilitate their sustainable and growing involvement as prime contractors in government projects nationally. Historically, small contractors - particularly those disadvantaged by the previous regime - were marginalised. They face many obstacles, particularly lack of access to information about contracts, finance, credit, or training in business skills. ECDP must be seen in the context of the South African government's transformation strategy and its drive to increase Small Micro and Medium Enterprise (SMME) participation in mainstream economic activity.

The programme is an important element of the DPW's policy to create an enabling environment and procurement reform within the construction industry to aid the advancement of those marginalised historically. As such it forms part of the Affirmative Procurement Policy which has been developed, taking account of international experience, to target specific groups for accelerated access to contracts.

ECDP's aim is to mobilise the synergy between the DPW, which has influence and contracts to offer, the emerging contractors themselves, and the private sector and non-government organisations, who have resources and support to contribute to overcoming obstacles facing emerging contractors like lack of business experience and access to finance.

The programme must, however, avoid creating a dependency syndrome. Ultimately it is intended as a role model for other clients at all levels of government to adopt.

Arup's role was to create a rigorous system, based on sound and clearly articulated principles, which could meet the government's requirement for fair, efficient, and cost-effective procurement while addressing the distortions of the past.

Definitions and categories

It was first necessary to define an emerging contractor unambiguously, based on the government's definition of an Affirmable Business Enterprise (ABE) - a small business, two-thirds owned and controlled by South African citizens who qualify as Previously Disadvantaged Individuals (PDIs) because they were disenfranchised under the previous regime.

It was decided that the programme would focus on the DPW's small maintenance, repair, and renovation contracts up to R2M in value.

1 top:
The logo for 'Sakhasonke' - 'building together' in the native language Xhosa.

2.
Contractor performing work delivered via ECDP.

Three categories were decided upon:

(1) day-to-day maintenance work up to R30 000 in value, for which the DPW is authorised by the Tender Board to place contracts on the basis of a few quotes from selected contractors off a roster

(2) tendered contracts from R30 000 - R200 000

(3) tendered contracts from R200 000 - R2M.

Rigorous entrance and exit criteria were established for each category. A contractor can progress from Category 1 to 2 and 3 depending on performance, and after satisfactory performance in Category 3 leave the programme with a certificate to facilitate, it is hoped, access to other contracts from the public and private sectors and to finance.

Essential components of the programme

The programme exists to create an enabling infrastructure in each regional office to provide emerging contractors with controlled access to work opportunities, combined with training and support programmes, and performance monitoring and evaluation throughout. It is founded on five basic elements:

- A database of emerging contractors, enabling them to be registered and categorised, and their progress monitored
- The DPW's stream of contracts suitable for emerging contractors
- Help Desks in the DPW's regional offices, equipped with the database and support systems and staffed to serve as contact points for emerging contractors
- Support in the form of training and access to supplier credit and loan finance, offered mainly by the private sector and NGOs
- Monitoring and evaluation of both contractor performance and of the programme.

The database and registration

The database is central to the entire programme. It contains full details of every contractor as supplied on the registration form and updated periodically, plus information about contracts bid for and awarded, contractor performance, and their progress in training and other support.

Ultimately the database will be integrated into the DPW's project management systems and falls in the ambit of their IT department.

For practical reasons it was decided to proceed with an ACCESS-based system which could be integrated later into the DPW's evolving systems.

The registration form has all the information needed to accept the contractor onto the programme as well as basic information needed for monitoring. The applicant's signature confirms acceptance of the DPW's rules and decisions. A similar form is completed annually by the contractors for monitoring purposes.

Proven contracting experience is not a requirement for admission into Category 1, but evidence of basic competence in the particular skill field, as well as basic literacy and numeracy and the ability to respond to phone calls and faxes, are required. The contractor must comply with the law for tax registration and other statutory requirements. There are about 40 separate skill fields, ranging from General Builder to Plumbing, Electrical, Painting and Pest Control. The contractor may register for one or more.

The registration form requires information covering:

- contact details
- statutory requirements
- bank and credit details
- ownership and management, with details of individuals and whether they are PDIs
- personnel and skills
- turnover
- experience and capability
- plant and equipment.

Help Desk Facilitators assist applicants with the registration process and check registration forms and categorisations.

The database programme carries out all the functions required to operate the system efficiently, and specifically:

- registration
- categorisation
- operation of the roster for Category 1 contracts, including identifying contractors to be approached for a particular enquiry
- recording all information about contracts bid for and awarded
- recording all data from the monitoring system, relating to contract performance and support
- report production to suit regional and national management requirements, including information about contractors registered, contracts awarded and performance.

3.
Contractors attending a meeting at the Cape Town Help Desk

Training

Training, particularly in business skills and management, is a primary component of the programme's support to participating contractors. A range of private sector training providers and NGOs throughout South Africa offer skills and management training to small contractors, but investigation showed none of them to be particularly suited to the business needs of small emerging contractors. The DPW therefore took two initiatives:

- to catalyse the development of an appropriate, generally available training programme
- to develop an introductory video and multi-media programme.

The Contracting Entrepreneurial Training Programme

The International Labour Organisation, plus the DPW and other stakeholders, obtained Department For International Development funding to develop this 12-module programme to address emerging contractors' specific business. It has the support of major training providers throughout South Africa and 50 trainers have been trained initially to offer it to emerging contractors. Formal monitoring will yield feedback on its effectiveness.

CD-ROM multi-media and video programmes

These are designed to address the basic needs of Category 1 contractors entering the programme. The video gives a basic 20-minute introduction, whilst the CD-ROM is more comprehensive and intended for use by the contractor at the Help Desk on registration.

It covers:

- a basic introduction to ECDP
- registration
- DPW procedures
- the responsibilities and expectations of emerging contractors
- test of their numeracy and literacy;
- specific guidance on the principles of tendering and how to prepare a quote.

4.
ECDP materials used at the Help Desk.

The Help Desks

These interface between the programme, the emerging contractors, and the public, so it was decided to create an image and design which is consistent, functional, and pleasant without being lavish.

An architect developed a standard design and specification for furniture and fittings, whilst communications consultants were employed to create the image and identity. They produced a logo and slogan 'Sakhasonke' ('together we build').

Initially the DPW decided to concentrate on six Help Desks at its regional offices, though ultimately the programme is intended to cover all nine provinces. As well as the Facilitators, each Help Desk is staffed by a specifically appointed Regional Programme Manager. The Help Desks are equipped to operate the database and the multi-media and training material, and contractors are encouraged to treat them as a 'home' for advice and counselling, access training and support, and formal assessment.

Organisationally the programme is located within the normal operations of the DPW, reporting to the Regional Manager, and all the departmental procedures relating to contracts are applicable. Facilitators are responsible for interfacing with operational units.

Communications

As well as developing the image and logo, the communications consultants advised on communications with emerging contractors and the public, including making contractors aware of the opportunities and encouraging them to register. They also assisted with public launches.

A set of material was developed, including posters for each Help Desk, a brochure explaining the programme, and a Newsletter issued by the DPW.

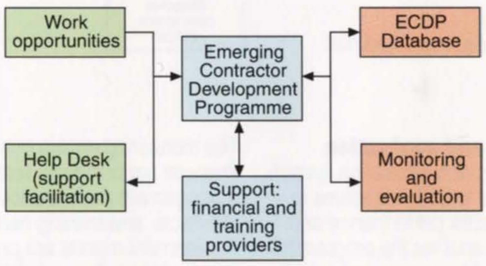
Support

At the outset it was recognised that the major problems facing emerging contractors are access to bank facilities, loans, and credit from suppliers, and training in how to run the business. These are specifically addressed in the programme.

Financial support

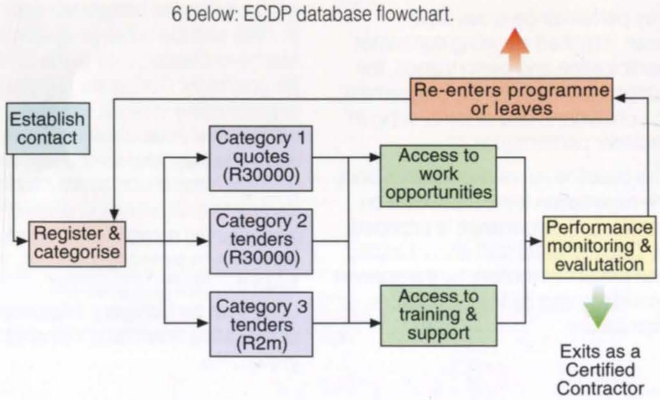
A major difficulty is the inability of emerging contractors to offer security, and the perceived credit risk. Another obstacle is the cost of administering small loans. Various mechanisms can alleviate this, such as cession of payments by the client, or the requirement for dual signatures on bank accounts, but these have the disadvantage of removing risk and financial control from the contractor and can be disempowering. What is needed is support for the emerging contractor initially, in a monitored environment which will ultimately lead to full creditworthiness.

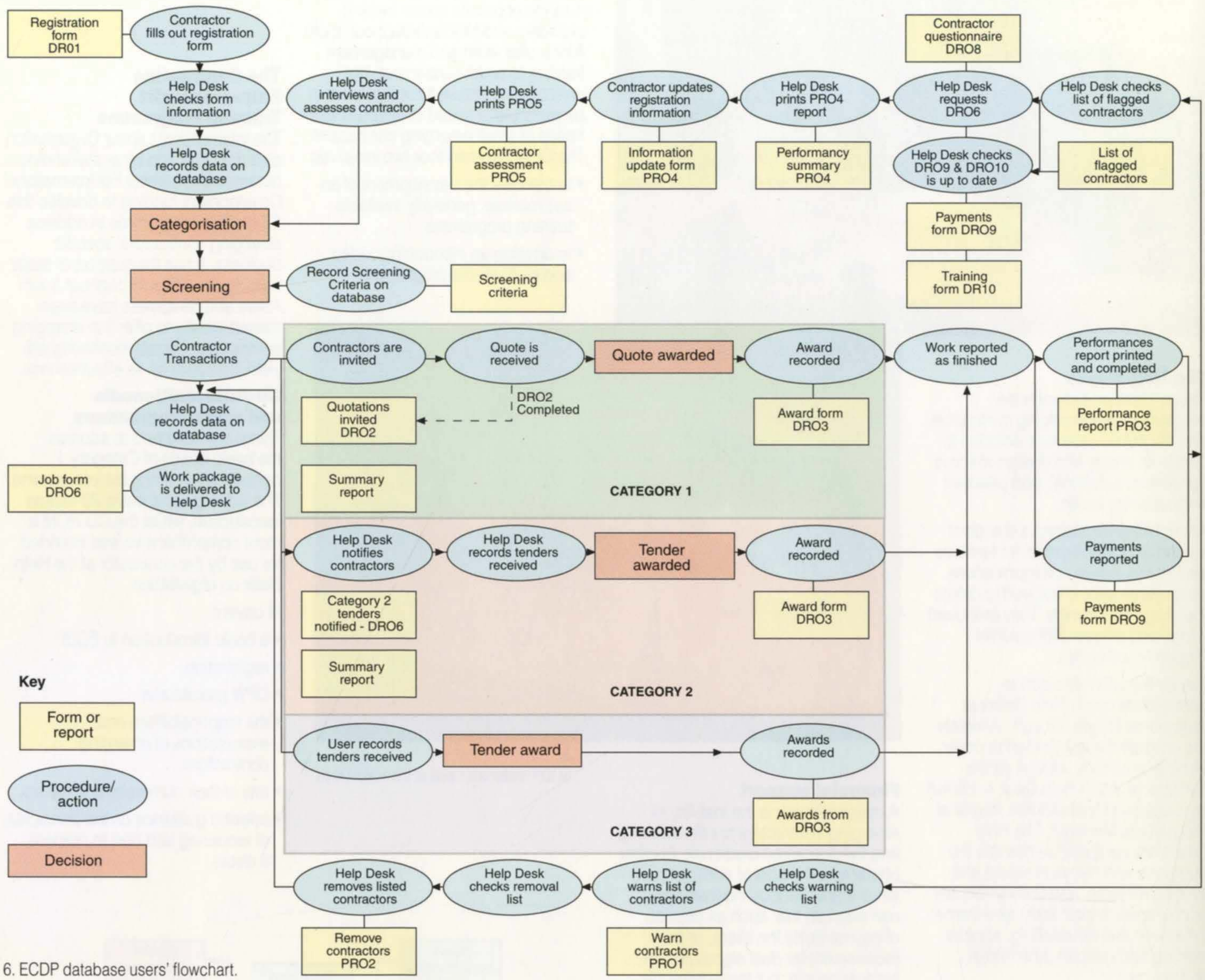
Negotiations were held with various financial institutions, NGOs, and suppliers, and measures explored to assist the emerging contractors. A scheme developed by Khula, an agency of the Department of Trade & Industry, gives guarantees covering 70% of the financial institution's risk and deals with procedural issues in the event of default. This facilitated the banks providing loans, particularly above R50 000. Below that the administrative burden remains an issue. Another vehicle developed with NGOs and banks, specifically for small loans for emerging contractors down to R10 000, involves the lending NGO being initially a co-signatory on the bank account, and the bank monitoring performance. Once the contractor uses a few such loans successfully, the bank will - subject to satisfactory performance - provide overdraft facilities itself.



5 above: ECDP key elements.

6 below: ECDP database flowchart.





6. ECDP database users' flowchart.

Monitoring and evaluation

The monitoring and evaluation system is fundamental to ECDP. It serves to assess contractor performance and progress, and enables the programme as a whole and its support services to be evaluated.

The system is incorporated into the database so that progress is consistently recorded and reported.

Key performance areas have been identified covering contractor participation and performance, the support provided by the programme to contractors, and external support provider performance.

The baseline information comes from the registration form. Input data on contractor performance is provided by Departmental staff about bidding and project execution; by the support providers; and by the contractors themselves.

The monitoring covers business and financial performance; technical and management performance on the contracts; and training performance. Assessment reports are produced for regular (normally annual) formal assessment of each contractor by the Regional Programme Manager.

Progress to date

Arup's brief to define and set up the programme was completed early in 1999 and the entire programme has been handed over to the DPW for operation. Contractor registration is proceeding in all six regional offices, and three of them - Cape Town, Durban, and Kimberley - are fully operational with several hundred contractors registered in each and a substantial number of contracts complete. A temporary difficulty has been the dearth of available contracts other than for Category 1 because of prevailing financial constraints in the DPW.

While aspects will naturally need adaptation in the light of experience gained during implementation, the programme is now operational, fully integrated into the DPW's management and procedures, with the capability of expansion to provide a broad platform for emerging contractor involvement in mainstream contracting throughout South Africa.

Extending the programme

The DPW always intended the programme to serve as a model for adoption by other client bodies, particularly at the national, provincial, and local levels of government and parastatals. Its potential will only be realised when the database, Help Desks and support systems serve each region's broad client interests. In the long term, it might be possible to adapt for other African countries the methodology developed in this specifically South African context.

The DPW has already engaged other client bodies in a process aimed at extending the application of its affirmative procurement policy, of which ECDP is a component, and presentations have been made to them. The rigorous concepts on which ECDP is founded should - with some adaptation - find broad applicability. This is the next priority, with which Arup hopes to be associated.

Credits

Client:
South African Department of Public Works

Consultant:
Ove Arup Incorporated Des Correia, Helen Crosby, Cliff McMillan, Nick Weinmann

Training programme consultant:
ILO

Multimedia programme consultant:
Tinderbox

Illustrations:
1:Tinderbox
2, 3, 4, ECDP
5, 6, 7: Jennifer Gunn

Housing: an exercise in industrial design

Graham Bolton
Paul Geeson
John Lyle
John C Miles

1, 2.
Arcon Mark V demountable house.

Introduction

The notion of building houses in a factory is not new; there have been many attempts to do it but, in the UK at least, they have never delivered a lasting and successful result. Reasons for this lack of success are complex but can be reduced to one principal factor: failure to meet the commercial imperative to produce the right product at the right price. The solution proposed in this article addresses this issue and its associated technical challenges. Though its context draws on UK experience, the solution is adaptable for global markets.

Background

The historic failure to perform commercially is exemplified by the prefabricated mass housing systems of the immediate post-war period. These houses delivered extraordinary levels of facility - including central heating, running hot water, and inside toilets - and could be erected extremely quickly with minimal construction error. Unfortunately, they also looked characteristically different from the norm (easily identifiable as pre-fabs), and cost more to construct than conventionally built houses of the time. When the hand of government was removed, no private developer would continue using an expensive system which delivered odd-looking houses, and the momentum of the factory-built housing initiative was lost.

A similar story emerged in the late '60s / early '70s when several excellent prefabricated panel systems were devised (along with some not-so-excellent ones). These offered better finished dwellings and quicker construction, but not lower costs per m^2 or much architectural merit. Again, without government subsidy, these systems fell into disuse in the hands of private house-builders, and disrepute following the Ronan Point collapse. (This and other technical 'black spots' considerably cloud the debate surrounding the final fate of the '70s prefabrication systems.) Clearly the Henry Ford dream, attractive in the abstract, is very difficult to achieve in reality.

A different approach

This history of unsuccessful approaches to factory house-building makes a successful future outcome more likely to arise from something radically different than from a further tweak to the historic approaches. Clearly, any lasting solution must focus from the outset on delivering the right product at the right price - and coupling the notions of performance and price is a discipline central to industrial design. It is in the nature of industrial designers to hold selling price as a key target, along with appearance, market acceptance, and performance, throughout the design cycle from conception to completion. If the housing problem is approached as one of industrial design rather than architecture, perhaps it is possible that a different, more commercially viable, result might emerge.

Hugely influential Modern Movement architects - Gropius, Le Corbusier, Buckminster Fuller, amongst others - devised quasi-manufacturing systems. These essentially involved transferring architectural and construction processes into the world of manufacturing. Our proposal is essentially the opposite: to transfer industrial processes into the world of construction...

Recent experiences

Arup has a strong tradition in innovative housing design and technology. Shortly after the War, the firm was involved in developing the Arcon system (Figs 1 & 2), and in the late '60s / early '70s, became a major contributor to the development of high-rise concrete panel systems (most notably, that marketed by Wates). During the '90s, we have returned to the subject and begun to explore the potential for the industrial design approach, completing several projects over the last six years.
The first was to develop a concept for high quality, low-cost housing systems suitable for high-rise construction in East Asia. This was carried out with Richard Rogers for a Korean client, and led to a steel / glass / reinforced plastic solution viable to 40 storeys (Fig 3).

Subsequent experience showed this solution to be unnecessarily expensive, but much was learned from this exercise.

3.
Industrialised housing system proposed in 1992 for Korea.

Then came a student accommodation block for the University of Cardiff, the initial engineering design of which was done by Arup's Building Engineering Division. This involved the delivery of some 60 student rooms, built in a factory and then brick-clad on site (Figs 4 & 5). The building was completed very quickly in a summer vacation and commissioned for use by students at the beginning of the autumn term.

4, 5:
Student accommodation, University of Cardiff.

Several more projects followed, culminating most recently with a low-cost, high-rise concrete system for a client in Hong Kong, and a system suitable for executive detached luxury houses for a UK client. The latter was a particularly interesting opportunity to bring together a truly multi-disciplinary team of architects (Arup Associates), car stylists (DRAL), engineers, production technologists, quantity surveyors, and market researchers.

The Ground Rules

These projects have been invaluable for developing ideas and identifying key issues. They show that, for this new approach to be successful, several clear ground rules directly relating to the dual needs of right product at right price must be established.

They can be defined as follows:

The First Rule of Industrialised Building (concerning the 'Right Price')

The added costs of a factory-built system must be balanced by reducing costs on site.

The cost of building conventional houses, excluding purchase of land and the marketing and sales costs for the finished product, essentially comprises materials cost + labour cost. (There are also some transport, plant, and equipment costs, but these are small.)

Replacing a conventional site-based process with a factory process inevitably involves capital investment. Also, the ongoing costs of operating the factory and cost of transporting products to site must be absorbed. If the factory process is to be viable, these new costs must be balanced by savings on site compared to the conventional process.

The conventional process comprises only materials cost + labour cost, the former is very difficult to reduce (apart from cutting wastage), since houses are built from the cheapest available materials in the first place. Any prefabricated design philosophy must therefore cut costs by reducing site-based labour to an absolute minimum.

Corollary to the First Rule
Volumetric systems must be preferred over 'panel' systems.
A great deal of conventional site labour cost is associated with installing and commissioning services, fittings and finishes, so these activities must be minimised. (These processes are not only labour-intensive, but also depend on increasingly scarce skilled labour, and have to be performed in a strict sequence which often gives rise to programming difficulties and delays.) Ideally, therefore, the product should leave the factory with all services, finishings and fittings fully installed, commissioned, and completed. This can only be delivered through a truly modular (or volumetric) approach in which complete rooms are shipped to the site already serviced, fitted, painted and decorated. This cannot be achieved through a panel system where the structure benefits from factory production, but installation of all services, fittings, and finishes remain traditional site-based activities. Preference for volumetric systems is fundamental to this production philosophy.

Delivering volumetric products implies transporting very large items mainly full of air. This is superficially unattractive but inevitable, and can be shown to be viable within the overall scheme of things. It also suggests the product might be inflexible, based around a small number of variations on the box theme. This can also be shown to be resolvable (see the Third Rule).

The Second Rule of Industrialised Building (concerning the 'Right Price')

The rate of producing products must be governed by the pull of what is required on site, rather than the push of what the factory wants to produce.

The primary issue in manufacturing economics is to keep production facilities in continuous use.

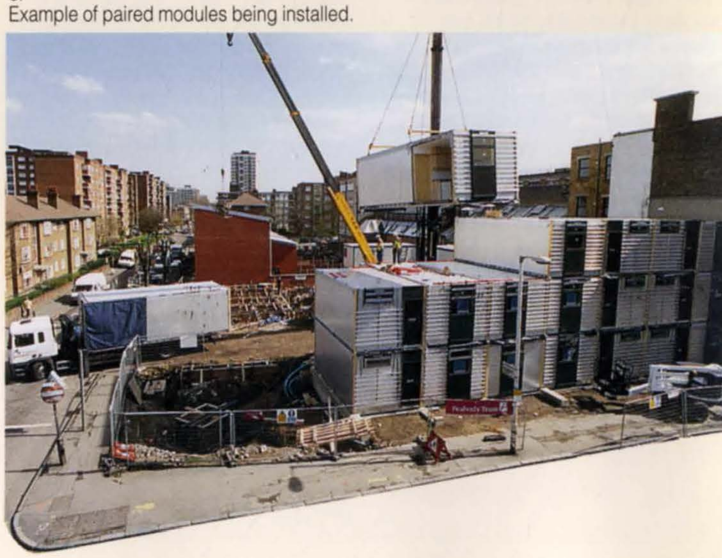
Discontinuous use of labour and capital equipment is very inefficient - an issue far more important to reducing costs than sheer volume of production (commonly regarded as the critical issue). It follows that a small, low-cost factory continuous in its production will be more likely to succeed than a large, high-cost factory where production is sporadic.

Another major issue in manufacturing economics is inventory control. It is widely acknowledged that it is uneconomic to store a lot of finished product at a factory pending delivery to customers.

There is thus pressure to synchronise production rates in a house-building factory with construction rates on site. Ideally, the inventory of finished products should be reduced to what is in transit between factory and sites (the perfect just-in-time system).

Corollary to the Second Rule
A factory-built solution involves more than just the transfer of the traditional product and process into a new environment.
If we try to replicate the existing product and site process within a factory, we have limited scope for improvement of quality or cost. By applying skills in design for manufacture and assembly (DFMA) and process design, we are able to improve product and process. As a result we must do more than simply transfer site-based processes into a 'shed' if we are to achieve the full potential of the factory-based approach.

6.
Example of paired modules being installed.



The Third Rule of Industrialised Building (concerning the 'Right Product')

No unreasonable constraints should be imposed on external appearance and internal layout by the factory-based production system.

Customer pull drives all successful products, so we must be able to produce (within reason) most types of commonly required house in any demand sequence. It would be fatal to get locked into a production system that constrains output to large batches of identical products. Consequently we must be able to produce a very wide range of different-sized modules (within certain extremes) from the production line in any arbitrary sequence. Each module, in effect, must be bespoke. This degree of flexibility in a low-volume production environment is commonly referred to as an agile production system.

Further, the system must be able to provide living spaces larger than the biggest single units transportable by lorry. The maximum practical load-width in the UK is just over 4m, but many houses demand spaces whose smallest dimension is more than this. This problem can be solved by making the structure in two halves which are then mated on site (Fig 6). Technologically, this is not difficult; it is the norm in constructing Japanese and US modular houses and UK fast-food restaurants, but it does increase site-based labour, and begins to depart from the pure ideas in the First Rule. Even so, the need to deliver large living spaces is an essential customer requirement and an ability to respond by producing mated pairs (or triples) is thus an essential production requirement.

These three fundamental 'Rules' will often be in conflict. As with any design problem, the solution lies in seeking a reasonable compromise and checking that the result does not fall so far from the ideal that it is rendered invalid.

The Solution

If we examine the UK housing market and seek to develop a factory-built product based on the Three Rules, the first questions must be: 'What is the product?' and 'What is the target delivery price?'. Housing associations and private housebuilders have very clear ideas of the right product and, to be successful, this is where the solution must start. (It is, of course, arguable that a completely different form of product might be desirable in the long run, but that can come later.) There are equally clear indicators on price, with typical construction costs - excluding landscaping and other site infrastructure items - running in the region of £330-£380/m^2. (Note: These are pure construction costs; they do not include land costs, marketing costs, and developer's profit).

The vast majority of UK new-build housing is low-rise terraced or semi-detached, with floor areas around 100m^2. There is also an increasing interest in building medium-rise properties (up to 10 storeys) but no requirement for high-rise development. The design challenge is to devise a system which satisfies the requirements of this market and is extendable to larger detached executive houses with floor areas above 150m^2. To avoid being stereotyped or stigmatised, it is important not to focus solely on low-cost housing and Figs 7-9 illustrate a range of possible interior styles.

The concept illustrated in Fig 10 comprises:

(1) A mini-pile and ground beam foundation system, chosen for speed of installation and ability to cope with a wide range of ground conditions.

(2) Six fully finished modules, delivered direct from the factory as pairs, stitched together on site.

(3) A concrete panel roof with tiles (or tile effect) on the outer surface. (Note: this system requires no roof trusses, leaving a completely free space for occupation).

(4) A site-built exterior skin of brick, stone or other material, depending on developer choice. (The pure ideal would be a panel exterior cladding system direct from the factory, but most housebuilders have expressed strong preferences for a hand-finished façade in traditional materials. This, at least, ensures that the finished product is indistinguishable from a conventionally built house, avoiding any pre-fab perceptions).

Before describing the factory process, however, the cost issue must be dealt with. A build price of £330-£380/m^2 was cited earlier. Of this, around half is material cost and half labour. If the latter somehow were an impossible zero, a maximum of around £180/m^2 per house would be released for activities introduced by the new system (factory costs, transport, cranage / placement on site, etc). The most rigorous real reduction of labour costs should actually release something like £110/m^2 - which sets some very real bounds on what can be proposed, and now becomes the primary influence in all that follows.

7-9.
The system must allow for a wide variety of client choice.

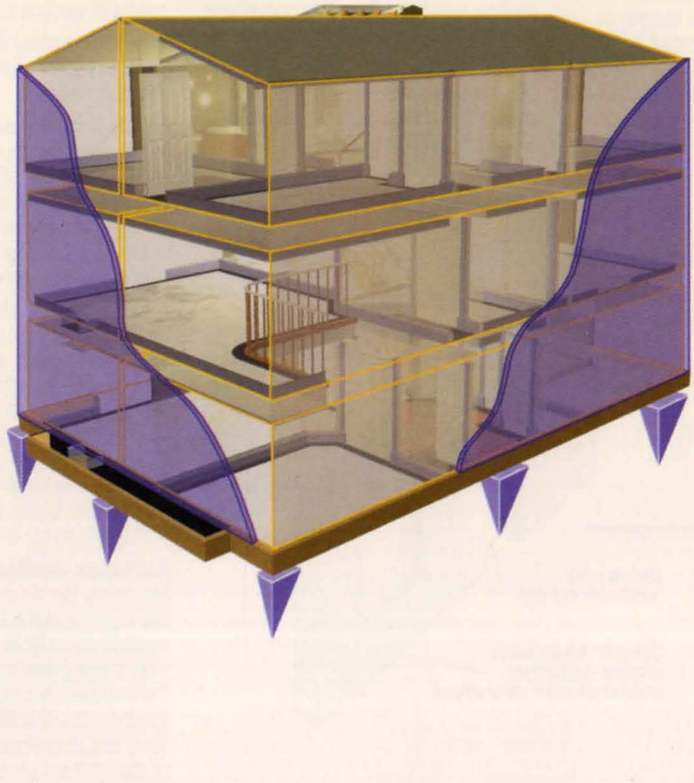
Overall process control

This starts at the point of customer purchase, drives the factory production sequence, and follows through to site works and customer acceptance. Ideally, process control should also extend to maintenance and such modifications as may result from accommodating later lifestyle changes.

Such a control process can be made available from an electronic database initially created at the point of sale to define the house plans and specifications.

This database can be extensively influenced by the purchaser's expressed preferences for particular fittings, internal layouts, and 'optional extras', and the sum total of information will then go to the factory to form the base data for the ordering, inventory, and production control systems.

As the product leaves the factory, the database will represent the as-built drawings and specifications and, on handover to the purchaser, become the service and maintenance document. Integrated within the 'optional extra' in-built IT systems, it will initiate equipment self-testing and issue prompts for service and maintenance visits.



10.
Formation of large house from modules.

Structural design and assembly

The concept requires a flexible system, assemblable in an inexpensive factory, using low-cost materials, with minimum wastage. Concrete is the obvious solution; it combines robustness with simplicity and has well-known characteristics. The obvious drawback, weight, must be considered but, provided a single module does not exceed normal transport limits (currently around 25t), even this may be deemed an advantage due to thermal and acoustic mass benefits.

To keep all-up module weights below 25t, an optimised thin-wall cross-section is required for the walls, floors, and ceilings. In addition the simplest possible layout for the reinforcement is needed to minimise process costs (Fig 11). This panel is simple to produce and may be used for walls, floors and ceilings.

The material cost is around £6/m², which compares very favourably with the direct alternative of steel stud / plasterboard drylined systems.

A good, sturdy, concrete panel construction is desirable for three reasons:

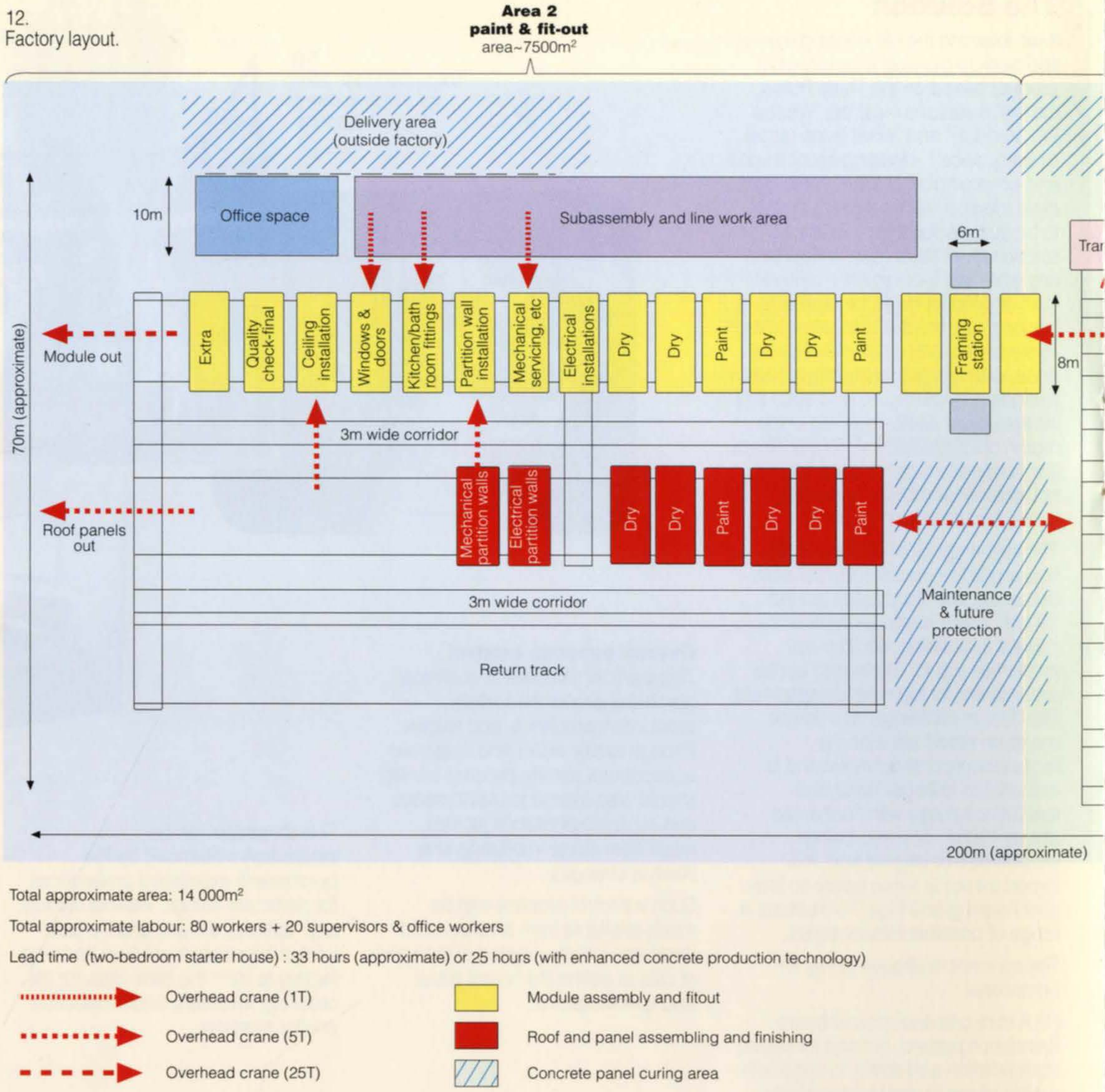
(1) It delivers the lowest possible material cost.

(2) It has the inherent strength for construction to multiple storeys without constant re-design of the basic configuration (a variant of this system was designed for 36-storey tower blocks in Hong Kong).

(3) With appropriately designed floors and ceilings, it can remove the need for interior load- bearing walls. This in turn allows considerable flexibility and customer choice over interior layout - a distinct market advantage.

The best way to construct the module shells is to produce six flat panels and factory assemble them in a purpose-designed jig before fitting-out during the later stages of production. Panels produced in this way can have extremely high surface quality, suitable for painting without further finishing (good for keeping process costs to a minimum).

12.
Factory layout.



Further, if the responsibility for dimensional control of the module structure is placed with the jig, the tolerance requirements at initial panel casting can be reduced to something achievable with cheap and simple formwork.

The flat panel casting system and assembly jig thus become the focus of the production system.

The jig must be rigid enough to hold six panels together to form a box with controlled dimensional tolerances, and also be adjustable for assembling boxes of various sizes.

It must also allow assembly of mated pairs or triples (boxes with one or two missing walls).

Finally, it must allow panel edges to be permanently connected relatively quickly. Each finished structure can then be removed from the jig and passed to the first station in the fit-out production line as a continuous process.

Customer wishes should never be neglected - for example, many will want to hang pictures on their walls. This can be accommodated by introducing a relatively thin layer of softer material, at time of casting, on the inside face of each panel - a solution practised in the '60s by some Continental panel-system producers and found to be very effective.

Services design

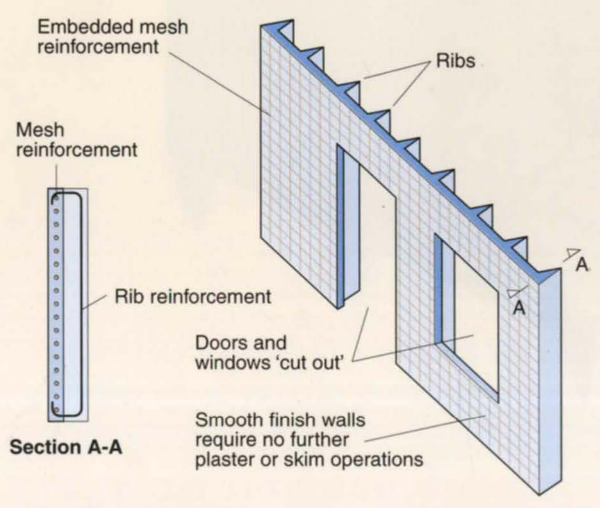
The main 'driver' of services design is the need to make quick, high quality module-to-module connections on site. These need to be made when the modules are brought together in the process of building the house. They are, therefore, key to the quality of the finished product, but the need for speed is paramount (the First Rule).

Ideally, there will be a single point at which services are connected from module to module, and the nature of the connections will be snap-fit or something similar.

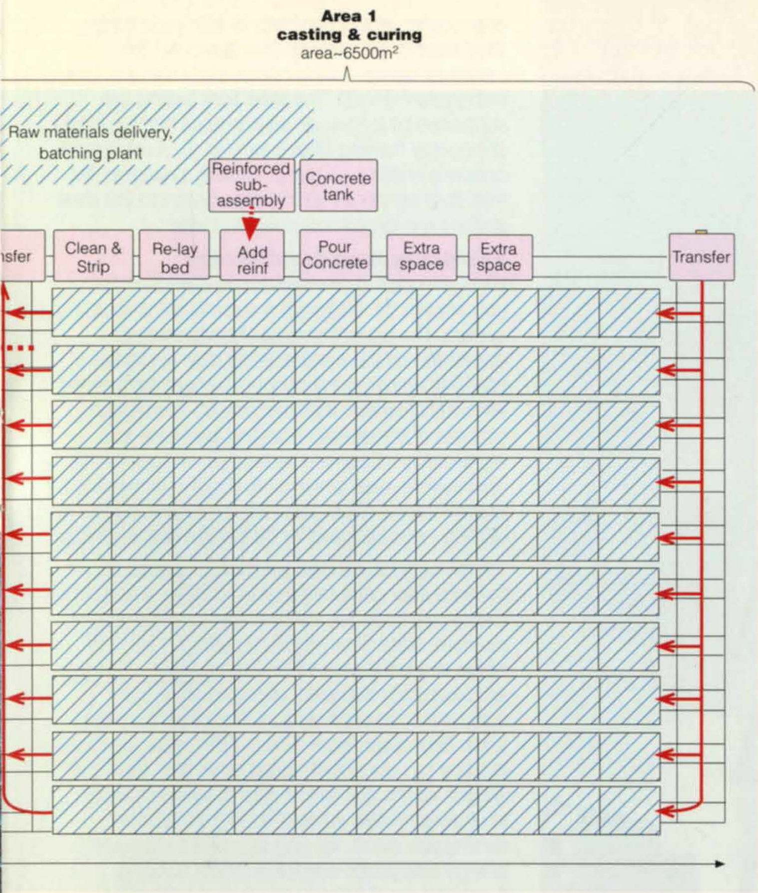
This means more expensive connectors, but the cost is counter-balanced by reductions in man-hours on site and a reduced probability that poor connections will need fixing at a later date.

Whilst on the assembly line in the factory, pipes and cables can for the most part be laid in ducts precast in the concrete panels. The production system must allow these ducts to be placed so that they can service radiators, lights, electrical sockets, etc, anywhere around the module rather than on a fixed 'service grid' (the Third Rule).

Once on site, the module-to-module connections must be completed within a few man-hours. This task is well defined, and identical to the site-based connections required for modular hotels and other types of modular buildings in the UK. Being, therefore, established practice, there seems no reason for it not to be practicable for housing.



11.
Typical panel showing reinforcement.



Production system design

An effective, low-cost, production system is the core of the design challenge. Without a process optimised to the needs of housing - which poses some very particular design and price requirements - it is not possible to deliver the right products at the right price.

This is the reason existing UK modular producers (making systems for hotels, schools, and fast-food restaurants) do not have a winning product in the housing field.

Working off the Three Rules outlined earlier, the proposed factory covers around 14 000m². Akin to a light engineering facility, it requires a large covered space equipped with jigs, tools, fixtures, conveyors, and several cranes up to 25t capacity (Figs 12 & 13).

The facility has the following important characteristics:

(1) It is sized to produce around 2000 modules pa on a single shift (representing around 0.5% of the national housing need).

(2) In the concrete casting shop, the panels are cast horizontally on steel tables (ideal for producing thin panels with a high quality surface finish).

(3) The fit-out production line comprises a series of stations with a dwell time at each of c50 minutes. This means that all the tasks allocated to a particular workstation must be completed within this time, and about eight finished modules per day are delivered to the factory gate.

(4) Pipework and cable runs are pre-assembled off-line in the factory, prior to being installed in the modules at the appropriate workstation. This arrangement might be improved at a later date by ordering pre-assembled sub-systems from suppliers, but this is not thought to be feasible initially.

(5) Computerised production control systems detail the components to be installed at each workstation (eg colour of bath, type of window, size of radiators, etc). This system works off the data contained in the original drawings for the house, supplied by the customer at the time of ordering.

(6) A workforce of around 100 permanent staff are employed, assuming single-shift working.

Including concrete curing time on the casting tables (12 hours), it would take about 33 hours for a module to pass through the factory and arrive, complete, at the factory gate.

The business case

The acid test for such a system working successfully in the UK lies in the soundness of the commercial proposition. It is counter-culture for house builders to consider large capital investments in anything other than land-banks and a good case must be made for returns on investment if the battle is to be won. This case can be tested from two different aspects - the factory owner's and the housebuilder's. Clearly, they do not have to be the same person.

From the factory owner's point of view, the factory described above, running at a steady 2000 modules pa production rate, can be shown to yield an 'internal rate of return' on the initial investment in excess of 45%. Payback on the investment would occur in Year Three, and operating profit on costs would be about 20% (very high for an engineering production activity). We do not believe the 2000 modules pa to be unreasonable: it represents a very small fraction of the current national new-build rate (c150 000 houses or maybe 400 000 modules pa).
It is also less than half the factory's peak capacity on two-shift working, seven days per week. There is thus plenty of reserve in the system.

From the housebuilder's viewpoint, the advantages lie principally in speed of construction and quality. Including foundations and 'brick skin', a pair of two-bed semi-detached dwellings could be built and completed in approximately five days (2.5 days per house).

This compares with three to four months for a typical conventional process with all the consequent implications for cash flow and poor quality. Potentially more significant, however, is the reduced need for skilled site labour - fast becoming a serious issue for housebuilders all over the country.

The Next Steps

Projections for UK housebuilding over the next 20 years suggest that the 150 000 units pa figure will rise (maybe even temporarily double). At the same time, there is an increasing shortage of site-based skilled labour - and customer tolerance of defects and poor workmanship is reducing. People expect their house to perform as well as their car, TV, and washing machine in terms of increasing performance and quality with no increase in price.

A well-designed factory-built product has the potential to resolve all of these conflicting demands. Arup is uniquely placed to combine leading-edge skills in architecture, construction, industrial design, and manufacturing to deliver such a product.

The proposed system can be shown to be economic, with relatively small production volumes and low levels of initial capital investment.

Over recent years, the firm has established some good relationships with housing associations and private housebuilders. Also, Arup has had a longstanding interest in applying the principles of good design to issues of social benefit.

The time is right to provoke change in the housing industry. Can we rise to the challenge? Time will tell.

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6. Yorkon Ltd
10. 'Alias' software from Topologies Ltd. / Denis Kirtley
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12. Emine Tolga
13. Trevor Loveland

13. Factory interior.

Resisting seismic forces: the CEC building, Taiwan

King-Le Chang
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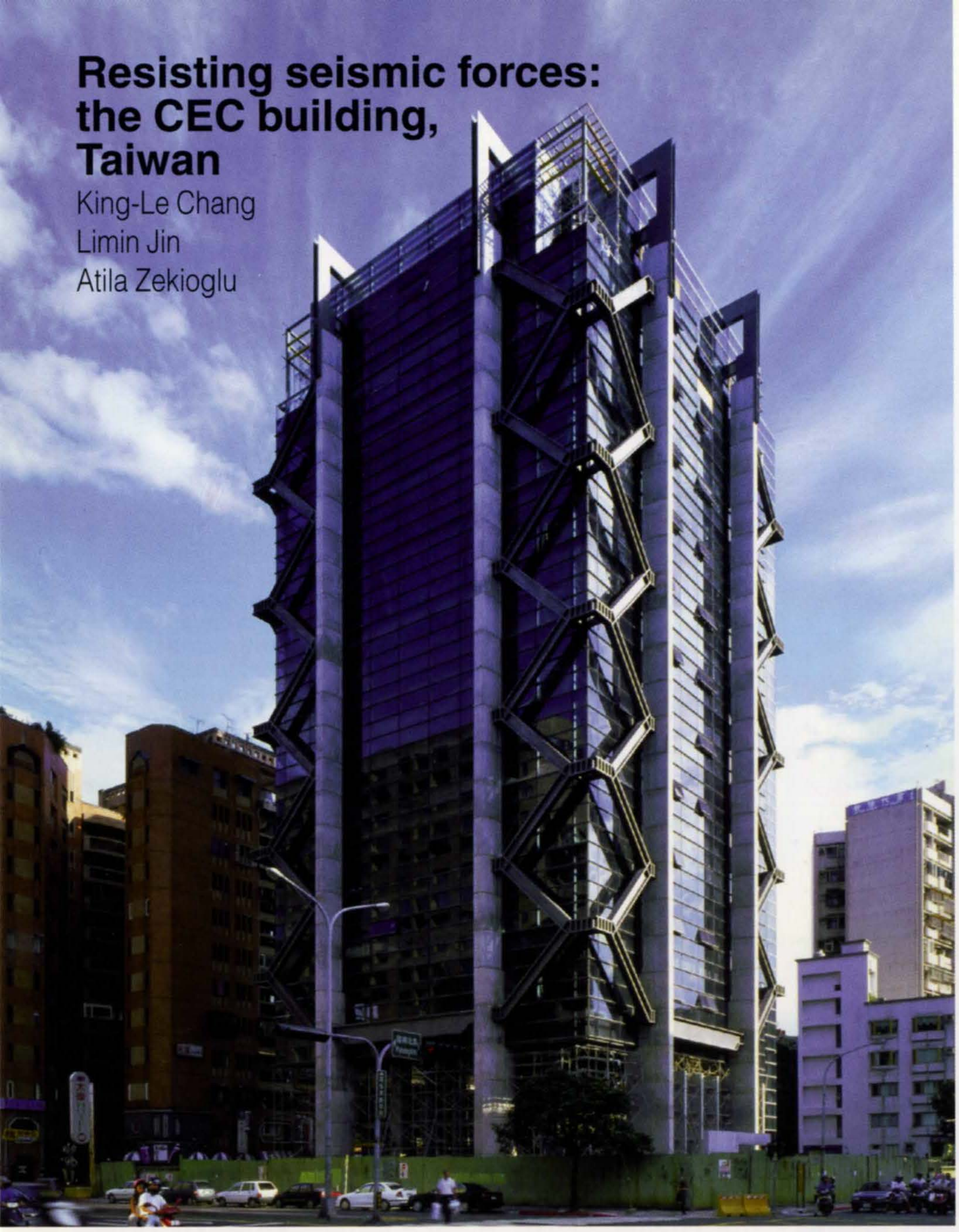


Introduction

The Continental Engineering Corporation (CEC) corporate headquarters building in Taipei, Taiwan, is a new presence on the city's skyline (Fig 1). The building has 17 572m^2 of gross office space, including a 13-storey, 60m tall office tower, two floors of meeting rooms and financial facilities, and four subgrade levels of mechanical and parking spaces.

CEC, one of Taiwan's most significant construction groups, wanted a structure that would epitomise its corporate identity. The complete integration of the exposed composite columns, the long-span steel trusses, and the exterior steel bracing with its separation from the tower floor diaphragm, creates a unique representation of the seismic force-resisting system. The design team included CEC itself; ARTECH Inc, Taipei, as project architects; Ove Arup & Partners' Los Angeles office as structural designers; and Supertech Engineering Consultants, Taipei, whose main responsibility was as independent design reviewers.

1 top: CEC headquarters, Taiwan.

Key design issues

These were four in number:

- to develop an exposed seismic-resisting system throughout the building's height that would not interrupt the column-free interior space
- to select an optimum structural system with enough torsional rigidity to improve the building's seismic performance
- to design a landmark structure, distinguished in both style and function
- to develop the site as well as possible within the regulatory constraints.

Tower framing

The architectural design resulted in an approximately symmetrical distribution of floor mass and structural framing[1]. However, the tower columns are typically spaced at 26.6m centre-to-centre in the principal framing direction and 12.6m in the non-framing direction to create column-free interior office space (and thus maximum future flexibility). These tower columns are composite above ground level, and reinforced concrete from foundation to ground floor to mesh with the basement reinforced concrete construction. For the floor plates, reinforced concrete framing was used from foundation to third floor, but above that they are formed by a composite metal deck and regular weight concrete fill with wide flange steel beams, typically spanning around 3m centre-to-centre, acting compositely with the floor slab system (Fig 2). The steel floor beams are supported by long-span steel trusses that run in two orthogonal framing directions (Fig 3). A reinforced concrete waffle slab/girder framing system at the third floor serves as an interface between the steel and the reinforced concrete structures.

Seismic system development

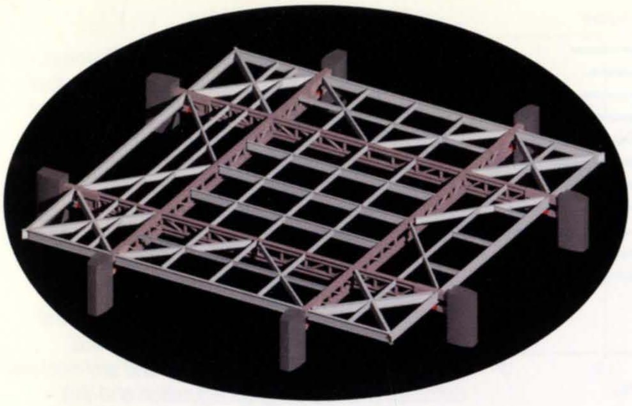
Wind and earthquake resistance were the prime concerns in developing the seismic force-resisting system. The tower's structural performance depended on the system being able to resolve a complex architectural concept without detrimental amounts of torsional displacement. The design process of lateral load-resisting elements was significantly influenced by seismic factors, and a dual seismic-resistant system (Fig.4) - eccentrically-braced frames (EBFs) and moment-resisting frames (MRFs) - was selected for the final structural design.

The primary lateral load-resisting elements above the third floor comprise four steel EBFs, whose link beams are folded at 90° to fit the corner shape of the main office floor (Fig.5), resulting in one EBF frame at each corner of the tower. All the EBFs are architecturally exposed, approximately 0.9m outside the façade line, and thus offset from the tower floor diaphragm. These EBFs were designed to carry no floor gravity loads other than their own weight. All the corner link beams were detailed to undergo shear yielding during an extreme earthquake event, serving as major earthquake energy dissipation elements for the building. A second set of link beams, their design mainly architecturally influenced, connect the EBFs to the composite column. To minimise complexity of structural behaviour, the architectural link beams were detailed to remain elastic under ultimate loading conditions.

Reinforced concrete space frames transfer seismic forces from the EBFs from the third floor to ground level. Additional two-way reinforced concrete space frames, with columns at 12.6m centre-to-centre, were placed at ground level to adjust the centre of the tower rigidity and control seismic drift from torsional movements. The secondary system of MRFs, provided for structural redundancy, comprises four 26.6m-span trusses moment-connected to the composite columns. The moment connection of the floor truss to the composite column was made by tying both top and bottom chords to the column. The four EBF frames were therefore coupled with the MRFs trusses through the exterior composite columns.

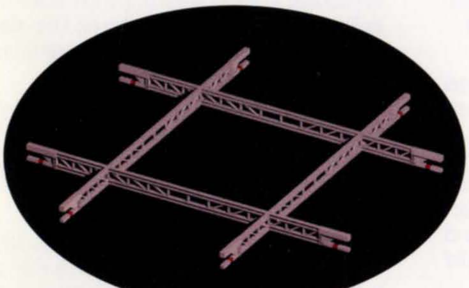
Site conditions and Taiwan Building Code

The project is in the Taipei basin, which covers some 24km^2 at around 20m below ground surface. The basin is filled with unconsolidated sediments characterised by a long predominant vibration period. Based on the local seismic code, Taiwan Building Code (TBC), the site is in a region of high seismic hazard. Moreover, in the Taipei basin, the seismic response of buildings with a fundamental period larger than 1.0 sec does not attenuate as rapidly as that in stiff and shallow soil conditions, because of the basin effect. Amplification of earthquake ground motions by near-surface geological conditions has been recognised as a major cause of damage in the Taipei basin. The site-response analysis from the past strong-motion records shows that a peak value of response spectra curves always appears at the period of 1.65 sec, regardless of the depth of sedimentary deposit. The maximum response spectrum value for the Taipei basin extends, therefore, to the point of T=1.65 sec in the Taiwan seismic code. Studies indicate that there is a significant difference between the elastic response spectra for buildings in the Taipei basin (from TBC) and those for the seismic zone 4 of soil type III in California (from the 1994 edition of the Uniform Building Code) (Fig.6).

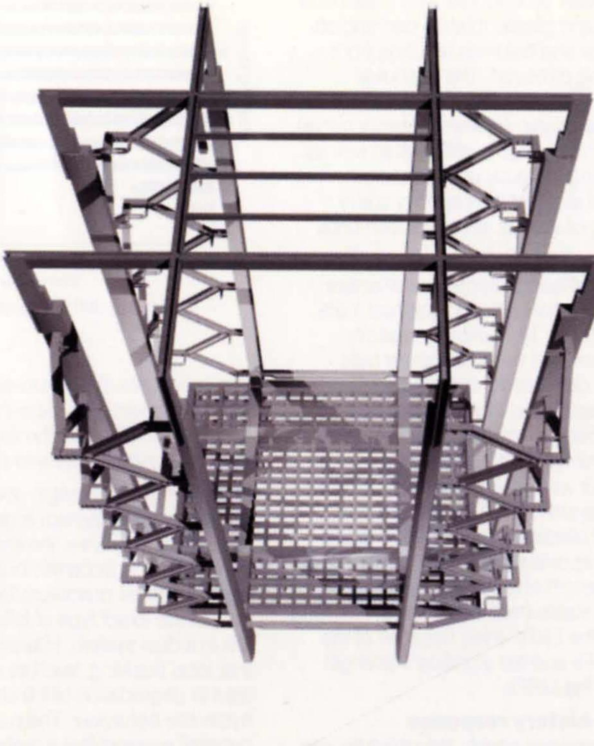


2. Tower framing model.

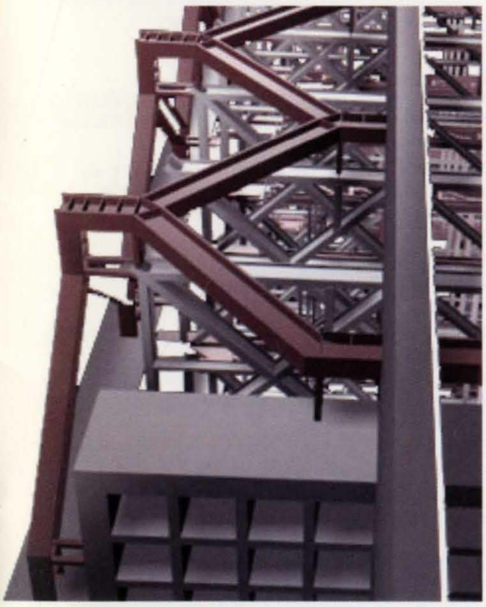
3. Typical floor framing.

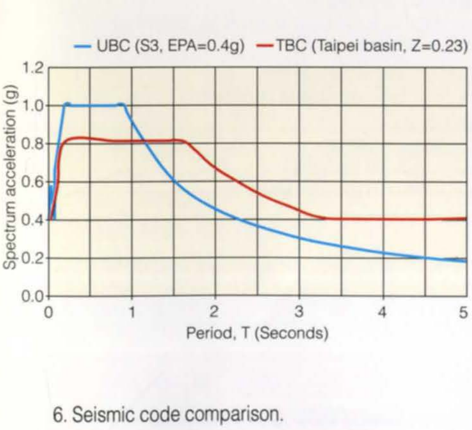


4. The dual seismic-resistant system: EBFs and MRFs.



5. Steel bracing at tower corners.





6. Seismic code comparison.

For a wide range of medium- to high-rise buildings, the minimum earthquake design base shear for the Taipei basin (from TBC) would be substantially higher than that for similar structures in seismic zone 4 in California; thus, the seismic force from the TBC was a governing consideration in the design of lateral load-resisting elements.

Processed ground motion records for the analysis of the CEC building were obtained from the Taiwan Strong Instrumentation Program (TSIP) to represent recorded absolute acceleration time history in Taipei basin. Peak ground acceleration (PGA) of 0.08g was reported. It is notable, however, that the duration of strong ground shaking is fairly long and the ground accelerations are rich with the period domain in the range of 1.0 - 2.0 sec.

The seismic hazard analysis for the Taipei basin[3], suggests that the estimate PGA value at Taipei basin is 0.23g for an earthquake event with a return period of 475 years.

Seismic system details

Because the EBFs are separated from the main tower, the floor diaphragms are not continuously attached to the lateral load-resisting system as in a conventional building. All the diaphragm forces have to be transferred to the EBFs through a set of floor diaphragm link elements. When loads are applied to each floor diaphragm, the forces pass through the floor diaphragm link elements and are then conveyed by the lateral system down to the foundations. This type of diaphragm-force transfer path was fully tested under various load conditions, and the most critical load combination identified from the highest level of resultant stresses in the floor diaphragm link element was used for the design and detailing.

The seismic response characteristics of the CEC building are highly dependent on the design of the EBFs' corner link beams, which are the major energy dissipation elements in the dual seismic-resisting system. The design of the EBFs' frame is based on the concept that, during an extreme earthquake event, yielding and damage to the system must be limited primarily to these link beams, which will deform inelastically with significant ductility and energy-dissipation capacity. The shear force demand on the corner link beams was first determined from the response spectra analysis, and the corresponding flexural capacity of the link beams was calculated. Once the properties of the corner link beams were defined, the rest of the EBFs' elements were sized, with the inclusion of the shear strain hardening effects of the link beam, such that they remain elastic during an earthquake event. For example, the member size of an architectural link beam is determined by increasing its shear yielding capacity to at least 1.5 times the shear capacity of the corner link beam. In addition, each architectural link beam is also designed to have a higher value of flexural capacity than that of its shear capacity to eliminate inelastic response under any unforeseeable condition. The detailing requirements for EBFs' link beams prescribed in the UBC were strictly followed. Each link-to-brace joint is laterally restrained at both the top and the bottom flanges of the link beam by two TS steel tubes. For the construction of the EBFs, the link beam corner connections and the link beam-to-brace connections are all shop-welded. Field splices are made only for braces where no yielding would be expected.

3D response spectrum analysis

Since the building is in a high seismic zone (Zone 4 of the UBC equivalent), and with an unconventional configuration of the EBFs in the seismic force-resisting system, a dynamic lateral force procedure was employed, beginning in the schematic design phase. The TBC design method was also used. A 3D computer model including the structural members both above the grade and at the basement levels was developed, using the design material properties and member sizes. The dynamic analysis shows that three significant vibration periods of the building are 1.67s in a translational mode, 1.64s in a translational mode, and 1.03s in a torsional mode. The translational model responses of the tower contribute to almost 90% of the total design base shear in each principal framing direction, which suggests that the seismic responses from the higher modes are negligible for this building.

This type of predominant fundamental model response may well be attributed to the rigid interface at the third floor. Because of its in-plan stiffness, the interface acts like a rigid platform that effectively reduces the number of flexible storeys, and thus reduces the higher mode contributions to overall seismic responses.

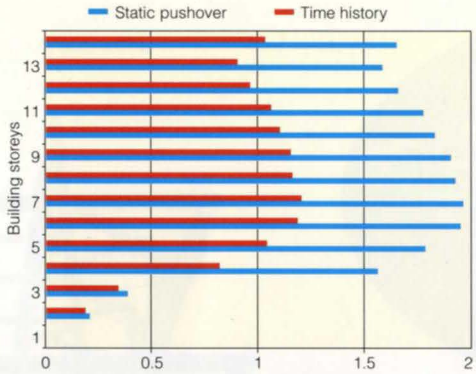
Inelastic pushover response

The main objective of inelastic static pushover analysis is to develop the building capacity curve using static pushover procedures, and to estimate inter-storey drifts and plastic rotation demand on shear links, beams and columns resulting from prescribed loading patterns[4]. The pushover analysis provides a base shear versus roof displacement relationship (system capacity curve), which illustrates the change in stiffness as well as lateral load-carrying capacity of a structure. The change in the slope of the capacity curve suggests yielding of various structural elements.

With the code-specified (triangular) and the first mode-based lateral load patterns, the structure was pushed until its roof drift ratio reached 1.5% and 2.1% respectively. The building capacity curves were determined with base shear ratio (V/W) versus roof drift ratio for these two different load patterns. It was found that the ultimate lateral load-carrying capacity of the tower is almost 2.7 times the TBC minimum design base shear, and inelastic behaviour was essentially confined to the EBFs of the dual system for all the storeys; the MRFs responded elastically until the inter-storey drift approached approximately 1.2%. It was also noted that the strength of the structure for all the storey levels was stable (non-decreasing) following shear yielding in the EBFs' links, because of the ductility of the EBFs and the significant strength contribution from the MRFs.

Inelastic time-history response

For seismic performance check, the structure was further subjected to recorded earthquake ground motions in the Taipei basin. The time-history records of absolute acceleration were scaled up to obtain seismic responses corresponding to the serviceability earthquake (SE: PGA=0.1g) and to the maximum earthquake (ME: PGA=0.34g). A damping ratio of 5% was used in the time-history analysis. The lateral force profiles were shown to be approximately triangular for the SE and approaching rectangular for the ME.



7. Inter-storey drift distribution.

The envelopes of inter-storey drift ratios from the static pushover analysis with the code-specified load pattern and from the time-history analysis (ME) were plotted together (Fig.7).

Since the lateral strength of eccentrically braced frames in a dual system is governed by the shear strength of their links, the shear links and their connections to eccentric braces must be detailed to prevent their premature failure. It is difficult to predict the exact type of failure mode of a shear link in a dual system. However, it has been found that local buckling, such as web buckling, would lead to degradation of the shear link's stable hysteretic behaviour. The published research papers[2] suggest that a realistic level of deformation in a shear link for the ultimate state is the level of deformation associated with the onset of link beam web buckling. The time-history analysis shows that the maximum plastic hinge rotations in the shear link at levels 6 and 8 are less than1.5% radians, and less than 1.0% at other levels. The building code has an explicit limit on the design of link beam. In the 1994 UBC, for example, the rotation of a link is limited up to 6.0% radians for a properly detailed EBFs frame.

Conclusions

EBFs are widely used in steel buildings because of their viability for earthquake resistance. A properly designed EBF coupled with MRFs offers the best choice of seismic performance and steel frame weight in line with the structural design objective and architectural constraints. In the CEC building, combining corner bracing with interior moment-resisting truss frames resulted in an efficient seismic force-resisting system in spite of the unusual EBF configuration.

The structural design and detailing of the lateral load-resisting system evolved: from an initial scheme based on seismic factors and architectural constraints on building configuration and drift control, to the development phase based on the seismic hazard analysis of the Taiwan basin, which in turn led to the final design. Both inelastic static pushover and inelastic time-history analyses were conducted to verify seismic performance of the building. The analyses focused on inter-storey drifts of the structure and inelastic behaviour of shear links in the EBFs.

The strength and deformation compatibility of the EBFs and the MRFs in the dual seismic resistant system were also evaluated, the results suggesting that the MRFs' trusses would develop their potential strengths during an earthquake.

The CEC building uniquely integrates architectural concepts and structural systems in a way critical to the office space and business development. The design and the construction of the building created a landmark headquarters for the CEC group in Taiwan.

Postscript

The challenge of creating a structure that could resist without damage the most severe seismic test was shown to have been successfully met when on 21 September 1999 the building survived Taiwan's 7.6 magnitude earthquake unscathed.

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K.C. Tsai, National Taiwan University

Illustrations:
1, 8: King-Le Chang
2, 3, 4, 5: Scott Hudgins
6, 7: Limin Jin / Jennifer Gunn

8. Corner detail of building as constructed.

Engineering the Reichstag Sign

Dieter Feurich   Raymond Quinn

Introduction
One of America's best-known artists, Jenny Holzer has produced large-scale installations at museums and other public spaces around the world. The messages in her artwork target society's prejudices, conflicts, and problems such as racism and sexism. For the Northern Entrance Hall (Fig 1) of the newly reopened Reichstag Building in Berlin, her commission from the German government resulted in an electronic scrolling-text column sign displaying historical speeches that reflect the history of the German Parliament or have in themselves become part of German history.

Jenny Holzer asked Arup to carry out the structural, electrical, and building information technology engineering design for the sign, following the then-recent completion of the engineering design and construction administration for a Helmut Lang clothing store in Manhattan, with Gluckman Mayner Architects, which included a Holzer sign. Arup was also asked to bridge any gap between the US and German parties involved, to help ensure the design would be acceptable in Germany and that the artist could successfully complete her commission - which included design, manufacture, delivery, installation, and commissioning of the piece.

Ove Arup & Partners New York undertook most of the design work, completing all construction documents in the German language. However, the team drew heavily from resources in other Arup offices around the world. Edinburgh provided an electrical engineer who, while seconded to the New York office, made good use of the Edinburgh-Berlin link to ensure the design complied with German codes and calculation methods. The expertise of the Advanced Technology Group (ATG) in London supplied a dynamic analysis of the structure. Arup Berlin provided local procedural and calculation method advice during design, and assisted in finding the local project manager to organise and supervise construction.

Despite the fact that the sign occupies only about 0.1m^2 of floor area, co-ordination and approvals required a tremendous effort from a disproportionately large project team. The manufacturing and construction tolerances required the Arup designers, led from New York, to carefully co-ordinate with the artist, the sign manufacturer, the building architect (Foster and Partners Berlin), the local structural, mechanical and electrical building engineers, and the Berlin project manager for the sign project. Also, the design had to be steered through the rigorous German approval process.

Engineering design
Each of the four 0.32m wide sides of the 14m tall sign-column comprises three individual, vertically stacked sections, forming a black plastic casing containing a computer-controlled matrix of amber light-emitting diodes (LEDs). All the sections attach directly to the sides of a central, structural steel tube, and meet at the corners to give the complete sign a cruciform cross-section. The bottom section for each side contains that side's microprocessor-based controllers.

The bottom of the central steel tube is restrained laterally by a second tube bolted to the floor slab and extending up inside it. A *Teflon* sleeve around this inner tube allows smooth vertical movement from thermal expansion and slab deflection. The inner tube also provides rotational restraint to the structure. This tube-in-tube restraint allowed the structural connection to be contained within the depth of the floor finish build-up. Similarly, the top connection was hidden above a ceiling panel so that the sign stretches from surface to surface and the text appears to emerge from the floor and disappear into the ceiling (Fig 2). ATG's dynamic analysis ensured that any laterally applied force would not deflect the sign's midpoint beyond acceptable limits, causing damage or spoiling the visual impact. To facilitate final site assembly, the tolerances of the German-made structural steel and the imported US LED-elements were finely co-ordinated. Before the sign sections were attached, the tube was painted with intumescent paint to meet German fire safety regulations for structural steel.

All the sculpture's electrical and data services are controlled from its main computer in a nearby control room. Electrical and data wiring is routed through the floor slab and connects to slave controllers at the sculpture base via flexible connections to accommodate movements in the sign and structure. All connections are hidden in the floor and the base of the sign.

1.
The sign from the exterior of the Reichstag northern entrance.

2.
Structural connections are hidden.

Conclusion
While the engineering design was relatively simple, its completion to satisfy all design team members and the regulatory authorities was not. The most rewarding aspect of Arup's involvement with this project was in assembling a multi-disciplinary and multi-lingual design team and use the resources and expertise of many Arup offices to work closely with a New York client to deliver a project in Germany. And all the better when that project is an impressive piece of art in a great building in one of Europe's great capital cities.

Credits
Owner:
Bundesbaugesellschaft Berlin mbH

Artist:
Jenny Holzer

Building architect:
Foster and Partners

Berlin project manager for sign installation:
Alexander Lubic

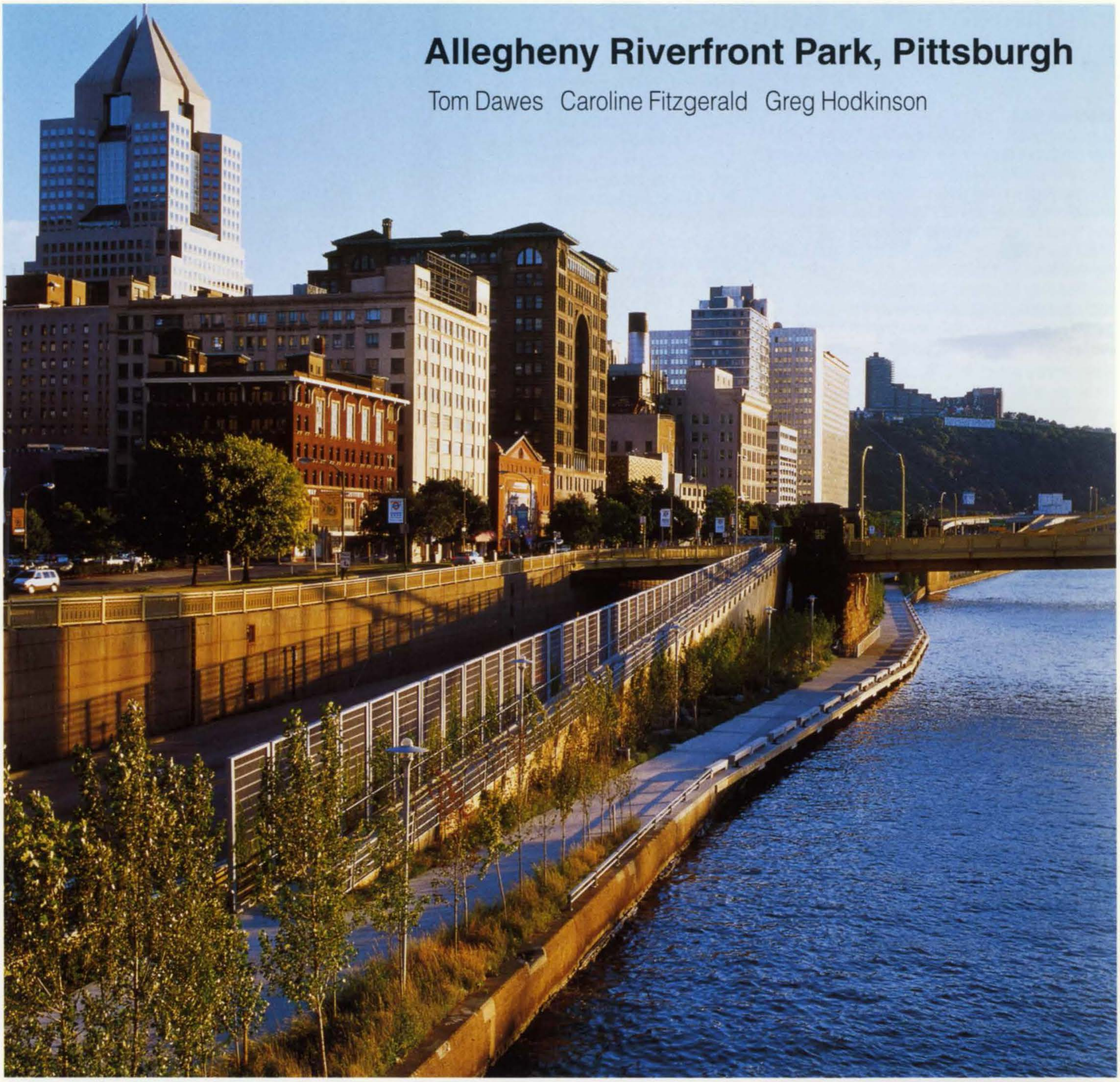
Engineers:
Arup Leo Argiris, Dieter Feurich, Anne-Sophie Grandguillaume, Jens Meirich, Nicos Peonides, Raymond Quinn, William Stevenson, Michael Willford

Photos:
Uwe Walter

Further information can be found at : http://www.bundestag.de/btengver/berlin/bonnberl.htm

Allegheny Riverfront Park, Pittsburgh

Tom Dawes Caroline Fitzgerald Greg Hodkinson



Introduction

At the start of every design process, engineers establish all their assumptions and design criteria for the project. For civil and structural engineers, as well as choosing the type and strength of materials, information about subsurface conditions is gathered and loadings are determined, usually from design codes. There are, however, rare instances when code provisions are inadequate. Such was the case with Pittsburgh's Allegheny River, for which there was very little historical data on flooding. The river flows 25ft (7.6m) below the northern side of the Golden Triangle business district, and has been separated from it by a river wall since the 1940s.

Near the completion of the construction document phase of the Allegheny Riverfront Park, the design team received a wake-up call from Nature. On the morning of 20 January 1996 a winter storm turned the normally placid Allegheny into a rage of ice floes which brought water almost up to the level of the city and covered the proposed park site to a depth of nearly 20ft (6m). The size and thickness of the ice was unprecedented in living memory. This event sent Arup USA and landscape architects Michael Van Valkenburgh Associates back to their drawing boards to re-visit the design assumptions and enhance the engineering in order to retain the original design concept.

1 top:
General view facing east of Allegheny Riverfront Park, showing route at river level around the abutment of Seventh Street Bridge.

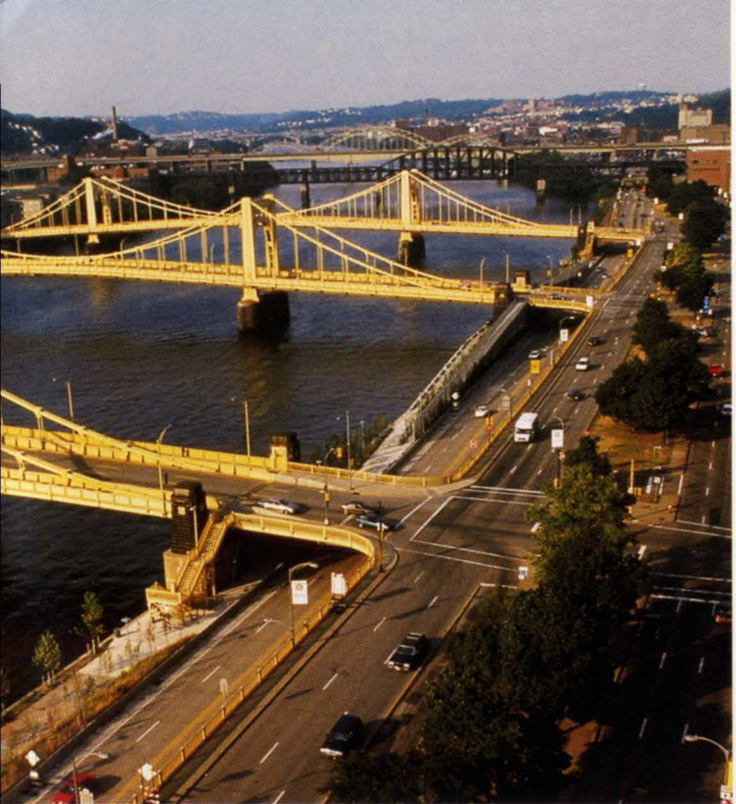
2 left:
Aftermath of the January 1996 storm.

Design

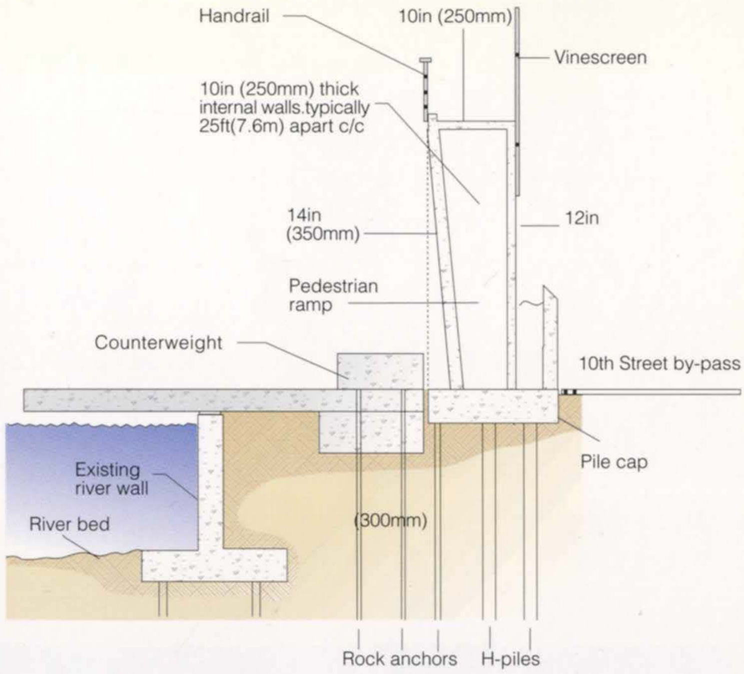
The Allegheny Riverfront Park is one of many projects generated by the Pittsburgh Cultural Trust, a non-profit organisation created in 1979 to foster the development of the downtown area into a cultural district. When they and the City authorities decided to develop this new amenity on the river's south bank, they envisioned exploitation of the river's edge itself.

For this notable commission, a design team comprising the Cambridge, Massachusetts-based landscape architect Michael Van Valkenburgh Associates, artist Ann Hamilton of Columbus, Ohio, and Arup USA was chosen in 1995 by the Trust from a field of eight finalist teams.

The design challenges of the site were formidable. The available land squeezes between a four-lane highway and the water. In plan, the park varies in width from 35- 50ft (10.7-15.2m), and is over 3000ft (900m) long, crossed by several high-profile 19th century steel bridges. This horizontal expanse contrasts sharply with the strong verticality of the city rising above the park. The team's solution uses ramp structures to reconnect pedestrians from the city level to the river, as well as providing an acoustic buffer to the newly defined space.



3.
Riverfront Park in relation to the bridges; Seventh Street Bridge is the middle one of the three suspension bridges.



4.
Structural cross-section.

5.
Decorative hand-rail designed by Ann Hamilton.

The review and approval process for the park was made complex by the multiple local, state, and federal public agencies that either owned adjacent structures or had jurisdictional oversight of the project. Over 20 departments in nine public agencies had to be consulted on every design and engineering aspect. Arup provided technical support on issues relating to flooding impacts, connecting the ramps to the bridges, existing bulkhead analysis, historically sensitive details, and utility co-ordination.

Starting at the Seventh Street Bridge, in the centre of the site, pedestrians are taken down to the level of the river via a pair of 6ft (1.8m) wide, 350ft (107m) long, cast in situ concrete ramps whose river face slopes down and tilts out, both at 14°, to give the impression of moving with the flow of the river. As well as reinforcing the ramp structure's walls to resist impact loads from ice floes, the internal crosswalls are supported on driven steel H-piles combined with 60ft (18.3m) long rock anchors to resist overturning instability. Complicating the layout of the ramp structural system was an existing Allegheny County sanitary main force line set directly below the footprint of the ramps. Supported by Arup's design studies showing the means for maintaining access to the force line, the County made an unprecedented ruling and allowed the ramp to be built over their utilities.

The southern walls of the ramps, which abut the 10th Street Bypass, are clad with galvanised steel 'vinescreens'. Each panel, 8ft (2.4m) wide by 13ft (4m) tall, will provide support to Virginia Creeper vines. On the river side of each ramp, galvanised steel panels are capped with cast bronze handrails designed by Ann Hamilton. Neoprene strips separate the steel and the bronze. The undulating form of the handrails contrasts with the straight geometry of the steel structure and reflects the movement of the river below.

River level

Here, a new river walk structure brings pedestrians and other non-motorised traffic along a pathway extending between the Fort Duquesne Bridge ramp at its western end and the Ninth Street Bridge at the east.

To continue around the solid stone piers of the Seventh Street Bridge, the walkway leaves the riverbank and passes out over the river, where it is supported on steel pipe piles driven into the river bed. These in turn are connected together with steel W-sections to form braced frames. When the contractor encountered difficulty in sealing off a coffer dam to make beam-to-column connections, Arup Research & Development specified underwater welding procedures.

The Army Corps limits the number of piles that can be driven into the bed of the navigable river, so the solution for the remainder of the walkway utilises 3ft 6in (1.07m) deep precast concrete girders at 25ft (7.6m) centres, cantilevering from the existing river wall by up to 18ft (5.5m). 10in (250mm) deep precast planks span between the precast beams.

Precise beam locations were adjusted on site as necessary to clear existing utilities under the site. Fixity at the base of the precast cantilever beams is provided by the top of the existing river wall acting together with rock anchors and driven piles at the riverbank end. In addition, solid concrete counterweights were incorporated into the design, giving a clear expression of the structural function. Low benches at the edges of the planks discourage adventurous gazers from accidental tumbles into the river.

The concrete paving that meanders along the rest of the park site was placed in two pours. The first was a 5in (125mm) thick reinforced slab on grade, whilst the topping slab was surfaced with a pattern of flowing blades of bulrush. Plantings for the site were chosen for their ability to survive floods; species like red and silver maple, native sycamore, and poplar thrive along local rivers. If cut off by ice floes they will sprout again with multiple trunks.

Conclusion

In November 1998 the Allegheny Riverfront Park Lower Level was officially opened, at a construction cost of $6M, to critical acclaim, having already won - part way through the design - a Progressive Architecture Award in January 1997.

Arup is currently working with Michael Van Valkenburgh Associates on Construction Documents for the Upper Level part of the project. Located on Fort Duquesne Boulevard at the city level, the Park is symmetrical about the Seventh Street Bridge and unfolds as two landscaped promenades. The 25ft (7.6m) wide by 2000ft (600m) long site is being created by the re-configuration of traffic along the boulevard. In situ concrete retaining walls and solid stone steps will create outdoor amphitheatres for performances or gatherings. Construction is expected to start in spring 2000.

Credits

Owner:
Pittsburgh Cultural Trust and the City of Pittsburgh
Funders:
Vira I Heinz Endowment; Commonwealth of Pennsylvania; Pittsburgh Cultural Trust Campaign for a Dynamic Downtown; Pittsburgh Water and Sewer Authority
Landscape architect:
Michael Van Valkenburgh Associates
Artists:
Ann Hamilton and Michael Mercil
Engineers and acousticians:
Arup USA Richard Bussell, Nathaele Dawes, Tom Dawes, Khalid Eid, Caroline Fitzgerald, John Giamundo, Greg Hodkinson, Tali Mejikovski, Richmond So
Civil engineers (Lower Park):
Frederic R. Harris, Inc.
General contractor:
C&M Contracting, Inc.
Illustrations:
1: Edward Massery; 2: Michael Van Valkenburgh Assocs; 3: Clyde Hare; 4: Emine Tolga; 5: Chuck Mitchell

Printed in England by Reedprint Limited, Windsor, Berkshire