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Front cover:
Legal & General, Kingswood. (Photo: Peter Mackinven)

Back cover:
United Overseas Bank Plaza, Singapore. Brian Simpson's Brick Model was used to analyze the soft clays in which the new 66 storey tower block was founded. (Photo: Ove Arup & Partners, Singapore)

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Arup Associates' new headquarters building for Legal & General Assurance Society Ltd. was conceived as a formal and sophisticated design to complement a Downland site of outstanding natural beauty.

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In his acceptance speech to the Royal Institute of British Architects on 29 June 1992, the late Peter Rice discussed his philosophy of engineering design, using as a case study the stone façade of the Pavilion of the Future, Expo '92 Seville.

Legal & General, Kingswood : Architecture in landscape

Architects: Arup Associates

Mike Bonner Don Ferguson

History

The Legal & General Assurance Society acquired the Kingswood Estate in Surrey in 1937 as a long-term investment in an agricultural property. The landscape of the Estate is exceptionally fine, lying on the chalk uplands of the North Downs near the Epsom Racecourse and extending to 183ha of mixed farmland and 32ha of mature broadleaf woodlands. It is bounded on its southern side by the wooded Chipstead Valley which rises steeply up onto the gently rolling plateau of the Downs, with long views north and east into open countryside.

Residential suburbs have grown up since the turn of the century and now extend along most of the southern and western boundaries of the Estate. An unusual feature was that, in addition to the two tenant farms and their associated cottages, a leasehold property also existed on the Estate's southwest side, adjoining the residential area of Kingswood. This was an elegant Edwardian brick gabled house overlooking the Chipstead Valley, occupied by a girls' boarding school and surrounded by the residue of its original terraced gardens and the various appendages of the school such as tennis courts and an open-air swimming pool. Although Legal & General's acquisition of St. Monica's freehold was only of secondary consequence to the purchase of the Estate, it became the focus for the almost continuous redevelopment at Kingswood over the last 50 years.

1. The 1955 building with St. Monica's in the background.

Legal & General's Fleet Street headquarters was destroyed in a bombing raid in 1944, and under the wartime Emergency Powers Act they moved out to Kingswood to occupy St. Monica's — enabling the girls to decant safely to Lincolnshire. During the immediate post-war years Legal & General continued to operate from St. Monica's and the various temporary buildings which they erected in the surrounding gardens. The staff clearly enjoyed the rural working environment and the Society prospered to the extent that these *ad hoc* accommodation arrangements became increasingly overcrowded and unsatisfactory. New permanent offices became necessary. However, rather than return all their commercial activities to the City of London, Legal & General decided to seek planning approval for a new office building on the Estate land immediately adjoining St. Monica's.

Although public awareness and concern over planning matters in the '50s was less vociferous than now, the application encroached on agricultural land within the Metropolitan Green Belt and the local community raised considerable objection.

The Secretary of State called in the application but, after a public inquiry, granted approval on the somewhat ambiguous grounds of being 'in the national interest'.

Construction began in 1955; the design — typical of many Modernist buildings of the period — did not endear itself to the local community. The building always appeared alien to its environment, forming no relationship with the existing St. Monica's, the site topography, nor the landscape of the Estate. It adopted a T-shaped plan placed directly into the valley gradients, requiring major excavation and contortion of the existing ground forms. It turned its main five-storey elevation to present itself squarely across the valley towards the residential neighbourhood beyond and, illuminated on a winter's night, it could be seen for miles across the Downland landscape.

The building, however, served its purpose well initially and the Society continued to prosper. A further planning approval was granted for extensions to the existing building in 1964 and the site population grew to some 1200 staff. In the meantime, St. Monica's was converted and extended to provide a generous staff restaurant, bars and recreation spaces, and the sporting traditions inherited from the original girls' school were enhanced to include cricket and football pitches, additional tennis courts, and the enclosure of the old outdoor swimming pool.

3. Commencing demolition of the old building.

2. St. Monica's reconstructed.

Impact of computer technology

The continuing expansion of data processing and its increasing integration into the operation of the Society created the need for more advanced computer facilities at Kingswood, and in 1976 planning permission was granted for an extension incorporating a new computer suite and associated plantrooms. In common with many large companies, the developments in computing technology continued to have major effects on the Society's operations and in 1984 a review indicated that further major expansion of these facilities would be required by 1987.

This second generation of computing technology would also bring micro-computers and screens to individuals in the office areas, in addition to the traditional centralized computer suites.

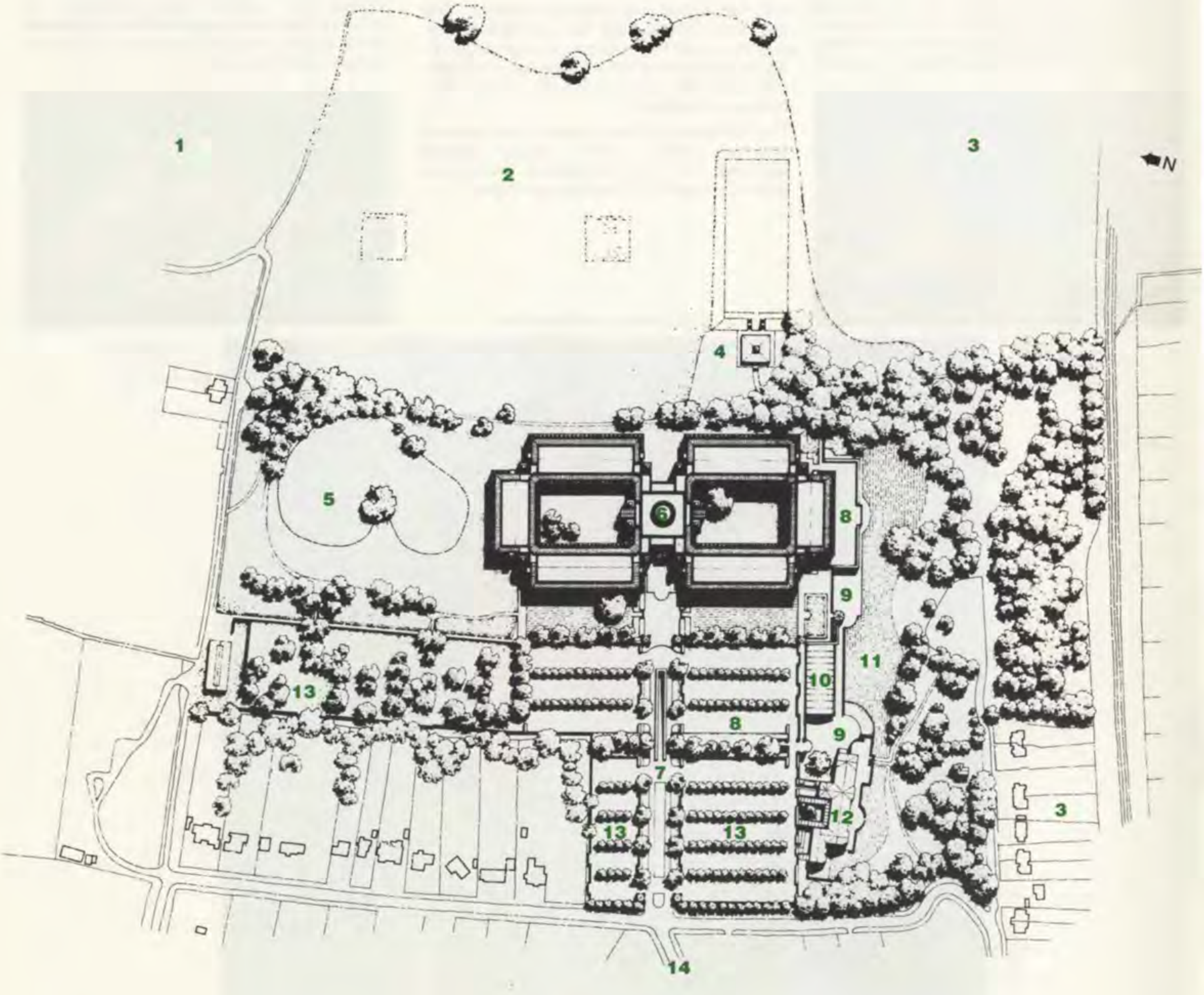
Arup Associates were appointed in 1984 to study the feasibility of upgrading Kingswood House to accommodate this new office technology, with particular regard to improving the working environment of the staff and overcoming the problems of increased heat generated within office areas by the new equipment — plus associated problems of lighting and glare. The resulting report concluded that full air-conditioning would be necessary and that the building did not comply with current environmental standards required by the Building Regulations. The existing structure had been designed with very low floor-to-floor heights, making the insertion of conventional air-conditioning systems difficult and expensive. Concurrent with the completion of the report, the Government introduced VAT on refurbishment of existing buildings which had the effect of further increasing the cost of refurbishment.

A new building

After careful deliberation, the Society decided that refurbishment was neither technically nor financially viable, and therefore to seek planning approval for the demolition of the existing office building and its replacement with a new design more suited to their current organizational and operational needs, in anticipation of the forthcoming Financial Services Act.

Arup Associates were appointed for this new commission in early 1985 and the brief was expanded to include the headquarters operation on the whole site including new office accommodation, St. Monica's and the various sports and recreational activities. There was, however, the very major constraint that the existing Kingswood House and all attendant support facilities, deliveries and parking for its 1200 staff remained fully operational until the new office building and its computer facilities were completed and commissioned.

In addition to its status within the Green Belt the Kingswood Estate and its surroundings had been further designated in recent years as an 'Area of Great Landscape Value'. Even so, the post-war developments around St. Monica's largely ignored this outstanding rural landscape and introduced a municipal scale and character to the buildings and their external spaces.



4. Kingswood site plan.

Key:
1. Kingswood Estate
2. Playing fields
3. Chipstead Valley
4. Cricket pavilion
5. Lake
6. Central Rotunda
7. Entrance avenue
8. Upper Terrace
9. Lower Terrace
10. Swimming pool
11. Terrace lawn
12. St. Monica's
13. Car parking
14. Approach from Kingswood Village

5. The main entrance.

The building in context

Arup Associates were concerned, now a new opportunity existed to reconsider the headquarters site as a whole, that this essential relationship with the adjoining Estate landscape be given full consideration and become the major architectural generator for the new development. There is little doubt that without the precedent of the earlier 1955 planning approval, a new planning application for a development of any size or purpose in the Green Belt at Kingswood would have been rejected, particularly a major corporate headquarters. This placed an additional responsibility on the designers to ensure that the new design was worthy of its unique setting whilst being responsive to the surrounding community and providing the client with a technically advanced building and pleasant working environment.

The overlaid landscape patterns which evolved in southern England in the 18th century and are so typically preserved in the Downland landscape are as much a creation of society as any work of architecture. They result essentially from the economic process of traditional agriculture, offset by contrived arrangements such as parkland, lakes and woodland coverts, and both the 'instinctive' and 'considered' positioning of buildings.

The 'instinctive' or vernacular form generally applies to small-scale buildings grouped as farms or villages, unsophisticated in character with simple elegant construction and materials drawn from the immediate vicinity providing close visual integration with their surrounding landscape. The 'considered' siting, however, is very much part of the alternative tradition of the great country house: generally formal, sophisticated and precisely made, often with imported materials and designed as a single building standing apart as a counterpoint to its surrounding landscape. In considering the design of the new headquarters for Legal & General, Arup Associates carefully reviewed these two distinct and contrasting precedents.

Some years previously a not dissimilar problem was addressed by Arup Associates for the CEGB Headquarters on Bedminister Down, and it was decided that on such an exposed hilltop site with a pronounced landscape of further hills and valleys, a discrete low profile form in the vernacular tradition was appropriate. That building became a visual extension of the hill itself with large roof pitches and rural materials to distinguish it from its urban neighbours across the valley in Bristol.

Initially it was felt that a similar rationale might apply at Kingswood, but in fact the context is quite different; the site does not stand out in the Downland landscape but is located at its edge from where it addresses the Estate rather than forming part of it. The precedent of the Surrey vernacular tradition in respect of the adjoining Kingswood Village is also misleading. The area may be perceived as responding to it but actually follows the ubiquitous stockbroker interpretation of 'vernacular': a dispersed suburban pattern of individual houses in their domestic gardens far removed from the real Downland vernacular of closely knit groups of buildings in open landscape.

To extend such a suburban pattern and domestic scale out onto the Legal & General site was wholly inappropriate in relation to both the Estate landscape and the considerable size of the headquarters building itself, particularly as the client was concerned to avoid a fragmented building and to maximize internal communication.

However, the alternative tradition of a formal building in a 'considered' relationship with its rural landscape did offer a precedent appropriate in scale and character to Legal & General, and it was this pattern of development which was adopted. There are of course many parallels between the great 18th century house and a 20th century corporate headquarters in terms of hierarchy, power, and wealth, but it was essentially the traditional relationship with landscape that was the underlying consideration at Kingswood and from which the design concept of the headquarters evolved.


LEGAL & GENERAL
HOUSE

Formal massing and layout

Although the site is located in a rural environment, the land actually available for development was as constrained as on many urban sites. The need to retain the existing office building during the construction period, the defined single site entrance, an existing public footpath alignment, and the site topography, effectively predetermined the location of the main headquarters building within very narrow limits. The area available formed a rectangle of some 200m x 100m, placed on the eastern edge of the site with its long axis parallel to the public footpath and the Estate landscape beyond, and the short axis facing the wooded Chipstead Valley.

Apart from the municipal characteristics of the post-war development at Kingswood, the most intrusive aspect of the 1955 building was its height and bulk. As the new building was to be considerably larger in area, it was clearly essential to minimize its apparent size relative to its predecessor, while retaining a stature which would reflect Legal & General's aspirations for the new headquarters. To achieve this apparent reduction in scale, a common 18th century landscaping device has been adopted. The site is bisected by a storey-height retaining wall on an east/west alignment at the point where the upland plateau drops into the southern valley. This creates two distinct and level terraces, with the lower at the original ground floor level of St. Monica's and the upper forming the entrance level to the headquarters building itself.

The office accommodation is arranged within the available 200m x 100m rectangle standing on this Upper Terrace. The new residential training accommodation within St. Monica's is complemented by the social and recreational activities of the swimming pool, sports hall, staff restaurant, bars and VIP facilities arranged on the Lower Terrace along the length of the storey-height retaining wall. This arrangement provides a clear distinction both in terms of location and scale between the business and social activities on the site, with the more formal and institutional scale of the headquarters building itself on the Upper Terrace and the more dispersed and domestic scale of St. Monica's and the social facilities on the Lower. This landscape device is extended with the provision of an additional floor to the office building located at the Lower Terrace level containing all the high security, service, and computer facilities supporting the offices above. This accommodation is entirely below the ground level of the Upper Terrace, so that when the main entrance is approached, nearly half the volume of the development is concealed from view.

The formal geometry adopted for the headquarters accommodation made it possible to achieve a very efficient plan within the limited site area available, and ensured that the new profile above the Upper Terrace be limited to two storeys. The resulting parapet datum matches the existing ridge line on St. Monica's and so dramatically reduces the height of the new development below the five storeys of the 1955 building. This discrete profile is far more responsive to the views across the wooded valley and the open countryside to the east.

A formal axis links the only permitted site entrance from the public road on Furze Hill directly across the Upper Terrace to the single main entrance to the headquarters. This is defined by a central Rotunda structure which forms the highest point on the development, rising above the two-storey parapet datum and giving the whole site a symbolic reference point. The Rotunda also creates the focal point for the internal organization of the plan, which is arranged symmetrically to the north and south around two courtyards.

The plan form of the headquarters building is heavily indented on the short entrance axis into the Rotunda, as well as on the four outer corners of the building to reduce its external bulk and articulate the façades into six distinct pavilions interconnected by the Rotunda and the staircase and service towers. This reflects Legal & General's investment requirements and provides a variety of scale responding to both the changing topography of the surrounding landscape and the staff needs for identification and orientation within such a large corporate building.

7. A belvedere on the Upper Terrace.

6. (Far left): The central Rotunda.

8. The social/recreational facilities on the Lower Terrace.

Architecture and landscape

A major proportion of the staff who were to occupy the new headquarters were accustomed to enjoying the views out of the old 1955 building, and were concerned that the deep plan form necessary to achieve the appropriate working environment for the new office technologies would limit their outside awareness. To compensate for this depth of plan, the façades of the office pavilions are 100% glass as perceived from their interiors, which creates a fully transparent envelope and ensures that a greater visual contact with the surrounding landscape is achieved from the new building. However, the consequences of such large areas of glazing is less satisfactory when viewed externally. Quite apart from the severe problems of glare and solar gain, the design team considered that an enclosing skin of metal and glass would be inappropriate on such a large scale without further articulation, and that the façades of the pavilions must do more than just reflect their surrounding landscape. They had to become an extension of the landscaping itself.

The articulation is provided by a freestanding screen comprising over-sized rusticated columns supporting a continuous timber pergola at eaves level and a timber maintenance walkway across the spandrel panels. Complete transparency is retained at right angles through the screen from the interiors, whereas the colonnade visually closes down from oblique external viewpoints to create the illusion of a solid wall which responds continuously to changes of light and shadow.

The pergola screen provides good high angle sun protection and supports automatic external blinds which lower to exclude excessive low angle sun from the interiors. The rustic columns support climbing plants growing up into the pergola above; in time the façade itself will become an integral part of the landscape in which it stands.

9. Climbing plants establishing on the pergola screen.

10. View back from open countryside.

The open variable character of the pavilion façades contrasts with the group of staircase and service towers which frame and interconnect them. These secondary elements are constructed without external openings in solid stone and brickwork, their lanterns raised above the line of the pavilion parapets to break their otherwise horizontal silhouette and complete the overall composition around the drum of the central Rotunda.

Landscape design

The foreground landscaping to the headquarters on the west side is arranged around a formal approach sequence via a broad, tree-lined avenue along the west/east axis leading from the site entrance to the Rotunda. The avenue is defined by walled gardens which adopt the formal geometry of the main building and enclose and conceal the majority of the on-site car parking from the adjoining residential areas. Specimen trees like Liriodendrons and Catalpas are used in this area, with a single species of flowering cherry planted at regular spacing throughout the parking areas.

A series of pedestrian walkways from the parking areas cross this foreground landscape, aligned directly to the staircase towers and their lanterns. They are defined by garden walls, arbours and lawns with piered gateways and pergolas at their intersections directing them towards the entrance forecourt and the raised central Rotunda. Climbing plants and flowering shrubs cover the walls, pergolas and arbour structures.

On the line of the storey-height retaining wall which defines the Upper from the Lower Terrace, staircases and belvederes provide vertical connections between these open upper level walkways and the covered colonnaded route at the lower level. This links St. Monica's training facilities with the various social and recreational activities arranged along and within the colonnaded wall.

This arrangement makes it possible to group together all these activities discretely with separate out-of-hours access independent of the working environment of the headquarters. Views extend southwards across the simple landscaping device of a level terrace of lawn running out to a precise rim from which the woodland drops into the valley below.

The formality of the terraced lawn creates a unifying foreground to the diverse and informally arranged social and recreational facilities along the colonnade, and provides a direct contrast to the irregular landscape of the valley woodland. This had become severely municipalized in the post-war period and a new management and replanting régime has been introduced to bring it back to a more natural woodland state.

A small irregular lake was proposed for the area immediately to the north of the headquarters building to continue the sequence of variety within the foreground landscapes of each of its four aspects. This compensated ecologically for the loss of several traditional dew-ponds from the Estate in the post-war years and established a dramatic foreground to the long views out into the countryside to the north. Grass berms and dense tree planting on the far side of the water conceal a pair of adjoining farm cottages and frame the outward view.

Additional grass berms on the west side conceal overspill parking from the walled gardens and dispersed irregular tree planting reinforces the old hedgerow planting which forms the boundary to the adjoining gardens.

The sequence of these foreground landscapes, from the formal avenue and its walled gardens, the terraced lawn and natural woodland, to the water and its reflections, culminates on the most open east side of the headquarters with the new playing fields and their characteristics of a parkland landscape.

To minimize their visual intrusion the changing-rooms serving the outdoor sports are constructed entirely below ground, with the adjacent outdoor tennis courts cut deeply into the valley contours and the woodland extended to enclose them, creating a backdrop to a small new cricket pavilion. The playing fields extend eastwards to a line of profiled earth berms defining their outer perimeter, with existing clumps of mature oak trees incorporated into the composition, framing the distant views.

These distinct foreground landscapes form an essential part of the 'considered' siting of the building, linking its formal geometry and pergola screens out into the surrounding landscapes and enabling the headquarters to become the focal counterpoint between the adjoining wooded suburbs and the Downland landscape of the Kingswood Estate.

Credits
Client:
Legal & General Assurance Society Ltd.
Designers:
Arup Associates
Architects + Engineers + Quantity surveyors
Landscape architects:
Peter Swann Associates
Main contractor:
Taylor Woodrow Management Contracting Ltd.
Photos:
1, 4-9: Peter Cook © Arup Associates.
2: Mick Brundle. 3: Chorley and Handford Ltd.

ESPRIT

Bob Venning
Steven Blackmore

ESPRIT stands for European Strategic Program for Research in Information Technology. In 1989, Arup Research & Development was approached by Thorn EMI's Central Research Laboratories to join with them and others in a project to produce various programs for use in the parallel environment of transputer-based machines. The project that AR&D were involved with was for the accurate simulation of the visual lit environment, which involved producing a front end program (EPALM) to define the model which would be passed on to the Lighting Visualization program (LVS) for calculation and rendering.

The first step was to produce a specification of what the users of such a program would need so that it was as user-friendly as possible, allowing the user to choose how complicated to make his model and how refined to make the analysis.

The input program (EPALM) would not only define the model to be analyzed but would also define the attributes of each surface and locate the luminaires. EPALM was a development of MPALM, an earlier Arup program developed for the representation and manipulation of geometric shapes; in fact the latter was completely rewritten with many additional features.

EPALM is a hierarchical program: it allows the user to start at a primitive level, then by grouping 'primitives' to create 'objects', grouping objects to create 'sets', and grouping sets to create a 'world' allowing efficient manipulation of sets and objects.

Standard three-dimensional primitive shapes can be generated, such as a sphere, cylinder, polygon, slab, luminaire, I-beam, and channel. The shapes can be chopped and split to produce sections of themselves. At each stage the model can be manipulated: it can be cloned to produce an array of identical objects, fanned to produce copies about a point, copied, or mirrored.

Data entry to EPALM can be carried out in a number of ways: either directly using a keyboard and mouse (or a digitizer), or indirectly from DXF files produced on a CAD system.

Whilst the latter may seem an obvious and very quick way of entering the dimensions of a space, in 1989 there were some drawbacks to this method, some of which still remain. At the time of starting the project there were no CAD packages on the market that allowed full three-dimensional object definition and manipulation, and which allowed attributes to be assigned to surfaces and objects.

What sort of attributes? To begin with, the colour: this is defined in red, green, and blue co-ordinates. Then there is the degree of reflection or specularity; this can vary from 100% diffuse (like blotting paper) to 100% specular (like a mirror); there is also the texture and patterning of the surface which give the image greater realism. One disadvantage in using CAD data is the amount of information stored. The art of using a visualization program is to simplify the model as much as possible without detracting from the viewers' perception of what he is seeing. If too much detail is used, the processing and rendering times are increased. The extra detail might actually detract from the perception of the final model or might not even be seen.

Once the model has been assembled, the surface attributes added, and the luminaires chosen and positioned, the data is passed to the LVS. The system allows the user to select the level of analysis to be carried out.

The program works on the basis of finite element analysis for reflected light and operates in two stages. The first considers each surface as reflecting sub-elements for dealing with both diffuse and specular light inter-reflection. A facility called adaptive subdivision allows areas where the illuminance changes rapidly to be analyzed in greater detail by subdividing the patches until a smooth transition can be achieved. This process can be aided manually as well allowing the user to employ his own knowledge and experience to concentrate the analysis in areas of importance. Obviously the more subdivisions there are, the longer is the calculation time. Finally, when the desired image is achieved, the specular imaging to a defined viewpoint can be added. Only this part of the calculation need be repeated for generating subsequent images from different viewpoints of the same scene.

Validation of the program took three forms:

(1) User reaction to different levels of detail.

(2) Comparison of output with photographs of the real environment.

(3) Mathematical check that the values calculated relate to the measured values.

70 people helped in validation check (1). The results of these checks gave indications of the degree of complexity needed to achieve acceptance, and hence the optimum level of analysis, above which changes in perceived realism becomes unnoticable. The results of check (2) can be seen on these pages.

Like all similar types of program, LVS is limited in its rendering ability by the characteristics of the visual display terminal. Contrasts in the range of 10 to 1 are all that can be achieved,

1 ▶

◀ 2

3 ▶

◀ 4

◀ 5

1-5
The basic primitive surfaces are broken down to smaller elements for the calculation of direct lighting. A technique called adaptive radiosity increases the number of patches where illuminance gradients are high so that shadows are shown.

6 & 7. An office in Arup R&D compared with a photograph of the scene.

6 ▶

◀7

8 ▶

9 ▶

◀10

◀11

8. A library refurbishment.

9. The floodlighting of a building fascia.

10 & 11. A micro-wave training tower simulated under daylight conditions and floodlit at night.

which is similar to a stills camera. The eye/brain mechanism can cope with much larger variations, so current screen technology can never produce images that can be a true picture of what we actually see, only an approximation. Another feature of the eye/brain mechanism is that whilst it receives light from a wide field of view, only a small proportion is in focus at any one time. The view shown on the screen is all in focus and consequently one 'sees' far more. Notwithstanding these limitations, lighting visualizations will have many uses. For instance, computer models can be made with more detail than, say, a 1:20 or 1:50 scale model which might be used for daylight testing. Changes to finishes are more easily made. Evaluations can be carried out overnight or at weekends, unattended.

The effect on the visual environment of different finishes can be tried prior to building a full-scale mock-up. Floodlighting schemes can be carried out simply and quickly. The building up of a furniture data base means that 'fitting-out' a space to give added realism is quick and easy.

However, experience in the use of the program and in lighting design are essential for the optimum use of the system. Continuing development will make the program more user-friendly. In addition EPALM has been adapted to act as a front end program to FABLON, providing a more flexible tool for this application.

Credits:
Client:
Thorn EMI CRL
Development engineers:
Arup Research & Development
Bob Venning,
Mike Schrire, Steven Blackmore

The Second S

Angu

▲ 1. Location of first and second Severn Crossings.

Construction has started on a new Severn Bridge three miles downstream from the existing suspension bridge. These pages record what might have been: the design which came a close second in the tender for the contract to design, build, finance, and operate the new crossing.

Ove Arup & Partners were appointed as lead designers for the joint bid by Trafalgar House and Balfour Beatty, and were responsible for the design of the bridge superstructure — all 5km of it — and overall design direction. The substructure and approach roads were designed by the bidders' own design departments. Arup Associates provided architectural assistance.

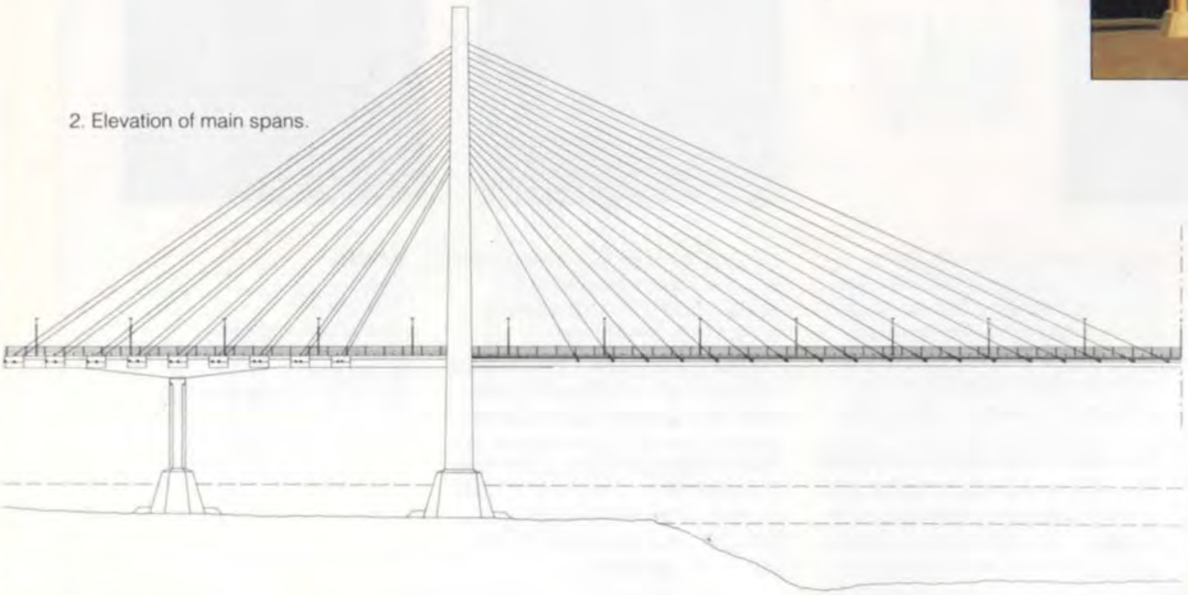
The brief from the Department of Transport was very detailed and included an indicative design. The alignment followed the 'English Stones route', named after a rock outcrop which is exposed at low tide over most of the width of the Severn Estuary. At the middle of the Estuary the outcrop is cut by The Shoots, a channel used by shipping, which requires a main span of about 460m. Near the English shore the alignment was curved to reduce the acuteness of its crossing with the railway tunnel. There were rules requiring the loads from the bridge foundations to be kept well clear of the tunnel.

Cleveland Bridge, part of Trafalgar House, had built the first Severn Bridge in the early '60s, and their memories of the ferocity of both tides and winds in the Estuary directed our brief. The design was required to minimize dependence on tidal working or waterborne activities, and the main span had to have the lowest possible susceptibility to wind excitation during construction.

These requirements dictated the main features of the Arup design.

▲ 3. Driver's-eye view of approach to the main span.

2. Elevation of main spans.



▼ 5. Telford's Me
in the mid-19th
reconstruction

evern Crossing

s Low

▲ 6. Model of precast post-tensioned concrete anchor span.

◀ 4. Model of main span and part of approach spans.

nai Straits Bridge,
century before
f the main span.

Aspects of the Arup design

- One carriageway of the approach spans was to be built as quickly as possible from both shores to supply the construction of the main span.
- Pier foundations on the exposed rock were to be concrete caissons, built in a dry dock and floated onto prepared level beds. Because of the horizontal stratification of the rock, little site preparation was required.
- The caissons relied on friction to resist the horizontal ship impact loads. For this they required large vertical dead loads, which were more easily achieved with longer spans.
- A standard approach span of 119m was chosen which was just long enough to clear the railway tunnel on the skew. Towards the Welsh shore the rockhead dipped and piles were required. Here, logic dictated shorter spans of 60m.
- The approach spans were to have precast post-tensioned concrete segmental decks, constructed as balanced cantilevers out from each pier in turn. An overhead erection gantry was to be used to deliver the segments, able to reach forward from a completed cantilever to the next pier so that all deck construction could be supplied from the land.
- The approach spans were to be taken up to the main pylons; the construction method dictated that their end cantilevers extended into the main span.
- A lighter construction was to be used for the main span, with steel box girders along each side of the deck in line with the cable planes, tapered in section to improve aerodynamic stability, and connected by transverse trusses supporting the concrete deck slab.
- Each half of the main span was to be built as a one-way cantilever with forestays added at each stage to the new section of deck, and backstays anchored into special crossarms on the final approach spans.
- It was recognized that a lighter bridge could have been built with two-way cantilevering from the pylons, but this would have been more responsive to high winds during construction, as well as requiring temporary spans to connect with the material supply across the approach viaducts.
- The wind stability of the main span during construction was further improved by the A-frame shape of the pylons.

This construction strategy was also the basis of the visual strategy. The visually strong approach spans were to be built from large but hollow concrete units of simple geometric forms, with the pylons following this precedent. They would have provided a strong identity for the bridge and a dramatic experience in perspective when viewed at speed through a sun-roof, with all the cables and the tapers of the legs converging high above the motorway.

From the side, the solidity of the approaches and the pylons would have emphasized the slenderness of the main span — a thin ribbon venturing out over the fearsome tide of The Shoots. A surprisingly close, 166-year-old precedent can be found at the other end of Wales, where Telford cautiously carried heavy masonry viaducts out to the pylons of the Menai Bridge (Fig 5), thus emphasizing the delicacy of his main span suspended high above the tidal whirlpools called The Swillies in the Menai Straits.

Regrettably, the Department of Transport gave the contract for the Second Severn Crossing to an Anglo-French consortium of John Laing, GTM Entrepose, and two banks.

Credits
Client:
Trafalgar House Construction
Lead designers:
Ove Arup & Partners
Architectural design:
Arup Associates
Illustrations:
1: Reproduced courtesy Ordnance Survey.
2: Ove Arup & Partners. 3: Georg Rotne.
4, 6: Harry Sowden.
5: 'Photophane' (Reproduced from a volume c.1890 illustrating The Forth Bridge, pub. Grant, Edinburgh).

The intelligent structure

Ian Gardner

The status quo

Almost all building structures throughout history have contained no means of identifying the magnitude of the loadings applied to them during use. Even fewer have contained any method of compensating for them.

For many structures, the only attempt at such compensation has been the precambering of beams and slabs to allow for dead load deflections. This precambering has often been anything but sophisticated, the hope being that on removal of temporary formwork the resulting deflections will cancel the specified precambers to leave the floor slabs level. Otherwise, no further means have been provided to adjust the structure. On completion, a structure is normally left to deflect of its own accord to find a form to match the external loadings and temperature effects acting on it. It is accepted that member curvatures, elongations and deflections will occur to enable the internal member stresses to balance out the applied loadings.

With this approach very little feedback is gained to benefit future building designs. Unless catastrophic failure occurs, engineers often have no knowledge of how near their structures ever get to the set design limits.

Commercial office buildings exemplify this lack of technical feedback. The floor loadings adopted vary widely from country to country and are often influenced as much by property funds and letting agents as by structural engineers. Engineers commonly accept this since they seldom have direct quantitative feedback from previous projects.

Stress-governed or stiffness-governed?

Many structures are *stress-governed*. The members are sized to suit their load-carrying capacities, which are determined by dividing their failure load by an appropriate factor of safety. Once the structure has been analyzed for the maximum expected loadings, and the members sized to not exceed safe stress limits, the design engineer can be said to have done his job. It is known that the structure will not fail.

However, many structures are *stiffness-governed*, and must be designed and sized to limit deflection under load: It is not enough to know that their members will not fail. Often they have to be increased in size beyond that needed to meet safe stress limits in order to give the structure sufficient stiffness. Examples of stiffness-governed structures are tall buildings and long spans. In conventional structural design, engineers have provided these types of structure with sufficient stiffness, or rigidity, to keep deflections within acceptable limits even when the structure is subjected to the maximum expected loadings. Occasionally for more sophisticated structures, jacking and post-tensioning have been used to compensate for initial self-weight deflections, or the sequencing of construction. Limited control of movement has been achieved using tuned mass dampers.

Conventional design: the passive structure

Typical present-day structures contain no means of compensating for applied loadings. Whether determinate or indeterminate, they merely react passively, without 'intelligence' or means of self-modulation to compensate for different loading conditions. They have no way of determining the magnitudes of the applied loadings or the actual configuration of the displaced structure, let alone self-adjustment to control stress levels or to maintain the structure's geometry.

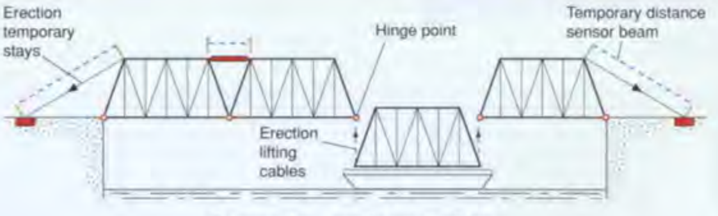
When designing such passive structures, engineers go to great lengths in analyzing movements which may arise, and developing details to allow for them. Expansion joints are detailed to enable one part of the building to move relative to another; equally elaborate details are provided to cope with movements of the structure under load relative to the cladding and internal fixings. Often these details are difficult to resolve fully and are amongst the commonest cause of problems during the life of the building.

Computer technology: feedback systems

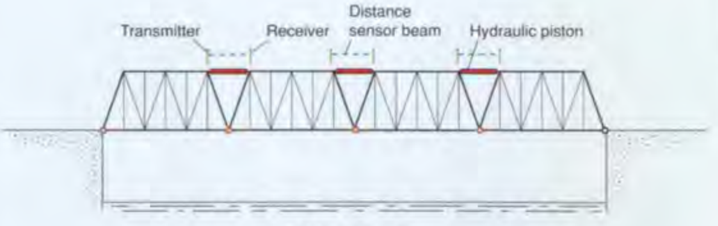
Building structures have not yet entered the computer age. Whilst their design makes extensive use of computers, the end-products — the structures themselves — do not. They contain no electronic systems and are still largely built of materials available before the computer age. There is no reason why this should be the case. Why should the structure not be linked into a building management system? The building services installations (lighting, HVAC, etc.) already often are.

Lighting systems can compensate automatically for the available external daylight to improve operational efficiency; air-conditioning can be used to maintain tight temperature control, and also to achieve reliably very critical pressure differentials between different parts of a building. In 'clean room' environments, the manufacture of electronic components or pharmaceuticals can be dependent on this precise control of air-conditioning.

It is also not always the case that a failure of the structure is more serious than a failure of building's air-conditioning. In some modern research facilities the containment of potentially lethal processes involving toxic chemicals or bio-hazardous materials, and thus the protection of the public at large, can be critically dependent on the pressure differentials maintained by the air-conditioning.

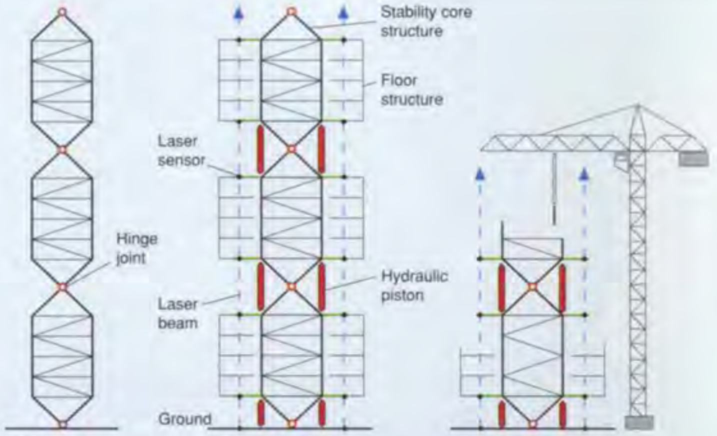


Construction - cantilever condition



Active structure

1.



Mechanism Active structure Construction

2.

Similarly microprocessors and ultra-fast electronic feedback systems are already used in other technologies. The public are happy to rely on such systems in aircraft, for their car engine management systems, anti-skid braking, and even their car suspension; many applications of electronic feedback and guidance systems are also used in military equipment. All work by continual testing for a deviation from the desired condition and immediately initiating corrective action if any is detected.

Great flexibility can be provided by having a range of pre-set requirements. The same feedback system can provide either optimum economy or optimum power output merely by resetting the conditions against which the system tests for deviations. Car suspensions can be made firm for optimum handling, or soft for optimum ride comfort, by the flick of a switch.

A mechanical engineer may be uncertain where in the air supply distribution ductwork the most representative check on diversity for the main air-handling plant can be made. To compensate, he merely puts in a number of monitors at different locations. Once the building is in use he can switch from one to another until the best control of the main plant is achieved.

For any system using feedback control, frequent monitoring is required to provide the feedback loop with a knowledge of the actual conditions. This can very easily be recorded, as with an aircraft 'black box'. A similar 'black box' in a building could be used to record loading conditions.

The active structure

With electronic technology, it must now be possible to design a structure with its own in-built intelligence.

Such a system might be a *controlled mechanism*. A conventional mechanism is a system which radically alters its configuration when disturbed. By the use of laser sensors and electronic microprocessors to provide feedback systems, it would be possible to detect and immediately compensate for the tendency of a mechanism to displace. In this way an active (rather than re-active) structure could be achieved.

In an active structure, its own intelligent feedback system would maintain the prescribed geometry regardless of applied loadings (or temperature effects).

Hydraulic pistons or other control devices would automatically be activated by the electronic feedback systems to compensate for any tendency to displacement. (Appropriate backup duplication of these systems could ensure adequate guarantees of safety against system failure.) Simplistic examples of controlled mechanisms or active structures are shown in Figs. 1 & 2.

On a smaller scale, long-span floor beams might be described as active structures if they contained a variable prestress. In post-tensioned reinforced concrete beams the tendon forces could be variable. In steel beams or trusses a tensioning device below the bottom flange could achieve a similar effect.

During construction of an active structure, the intelligent electronic feedback system would be used to compensate automatically for temporary construction conditions, e.g. monitoring a cantilever bridge during erection.

Also, for tall buildings an active rather than passive structure, with its own intelligence and ability to self-correct its geometry, could have advantages: the main core structure could constantly stabilize itself both during construction and after completion. If initial planning or rights of light restrictions on building height were subsequently relaxed, an active system could provide a method of compensating for the increased loadings of additional floors or infilling of floor set-backs.

Other benefits

The active structure approach could be used to maintain either geometry or constant stress levels. Instead of variable tensioning devices in a beam to compensate for increased loading, others could be used to vary separation between compression and tension flanges. The lever arm could in this way be adjusted to support different loadings without changes in stress.

The use of active structural systems to maintain geometry could contribute to vibration damping. The feedback system would detect the displacements associated with vibration and act to negate them and thus enhance the available damping.

On a larger scale, an active structural system could be programmed to limit peak accelerations. Rather than attempt to prevent displacement totally, it could be used to give a building structure a level of controlled 'softness'. This might be particularly useful when designing to cater for seismic loadings. A tall building structure could under normal conditions be programmed to maintain a fixed geometry, but under the particular loadings arising from seismic action the same control system could automatically switch to a different response behaviour, which might deliberately allow sufficient displacement to avoid the extreme peak values of acceleration which tend to cause so much structural damage.

Summary

The active structure concept would provide the designer with great scope to tune a structure's behaviour, and release him from the constraints of stiffness-governed structures. The only constraint would be stress.

'Soil behaves like bricks on strings'

Brian Simpson

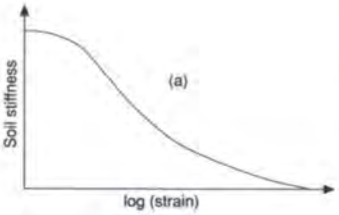
The annual Rankine Lecture is the most prestigious event in the British Geotechnical Society calendar. Brian Simpson was the second member of Arups, following David Henkel 10 years ago, to be honoured with an invitation to present it. This article is an abbreviated version of part of his 32nd Lecture, presented in March 1992 under the title 'Retaining structures — displacement and design'. The early part dealt with some aspects of retaining wall behaviour and their relation to the safety provisions of codes of practice currently under development. The Lecture then considered the observed ground movements at British Library, Euston, comparing predictions made during the design. Both these items led to the need for better numerical modelling of soil behaviour, and a new approach to this formed the basis of the third part of the Lecture which is also the subject of this article. The paper based on the complete Lecture was published in Géotechnique, December 1992.

Introduction

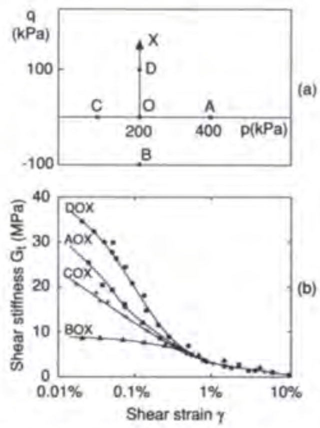
During the design of the British Library, the importance of soil behaviour at strain levels much lower than normally measured in laboratory tests began to be apparent. This led to the development of an early model of the behaviour of London Clay[1]. Much recent study of soil behaviour has centred around the type of diagram shown in Fig.1, often referred to as the S-shaped curve, which shows how soil stiffness is high when strains are small but reduces as straining proceeds. Strain is usually plotted on a log scale for this purpose. The new proposal made here is that this important feature of soil behaviour — and several others — can be reproduced by study of a very simple analogue: a man pulling around a set of bricks on strings!

In an SERC project at City University, supported by Arups, Richardson[2] made a set of triaxial tests on reconstituted London Clay, concentrating on accurate measurement of small strains. He consolidated specimens to point A in (p,q) space (Fig.2), where p is the mean normal effective stress on the soil and q is the deviator stress (double the shear stress). He then studied stress path OX, for which p is constant at 200kPa. He took specimens from A to OX by various routes, such as AOX, (AO)BOX, (AO)COX and (AO)DOX. In each case he studied the stiffness of the specimen for the final path OX.

Plotting tangent shear stiffness against log(shear strain), he obtained the S-shaped curves shown in Fig.2. He found that the highest stiffness along OX occurred for path DOX, which included a 180° reversal in the stress path at O. AOX and COX, with 90° turns at O came next, and BOX, which passed straight through O, gave the lowest stiffness for path OX. The soil readily continues straining in the direction it was previously moving (BOX), but is much stiffer if made to change direction, especially for 180° turns such as path DOX. Later work by Stallebrass[3] showed that the soil tends to keep straining in the direction it was previously going, even when the stress path changes direction abruptly.

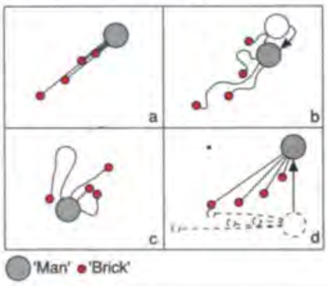


1. The S-shaped curve.



2. Results obtained by Richardson[2] for stress path OX: (a) stress paths; (b) S-shaped curves showing tangent shear stiffness.

3. A 'man' pulling 'bricks' attached to him by strings.



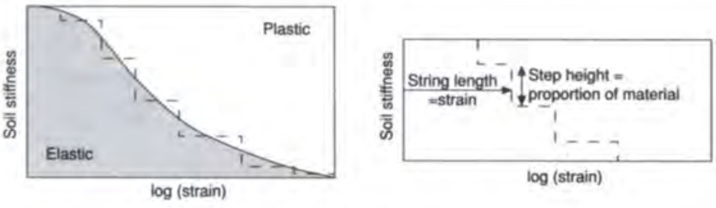
An analogue

Imagine a man walking around a room and pulling behind him a series of bricks, each on a separate string; Fig.3 shows some possible paths. If he walks continuously one way the bricks line up behind and follow him (a). If he turns back (b) the bricks initially do not move; then the ones on shorter strings start to move, gradually followed by the longer ones (c). If he turns through 90°, the bricks initially keep moving in their previous direction but gradually swing round behind him (d). The similarity to soil behaviour is obvious, but the analogue's use is less clear. What would the bricks and strings represent and what are the axes of the 'room'?

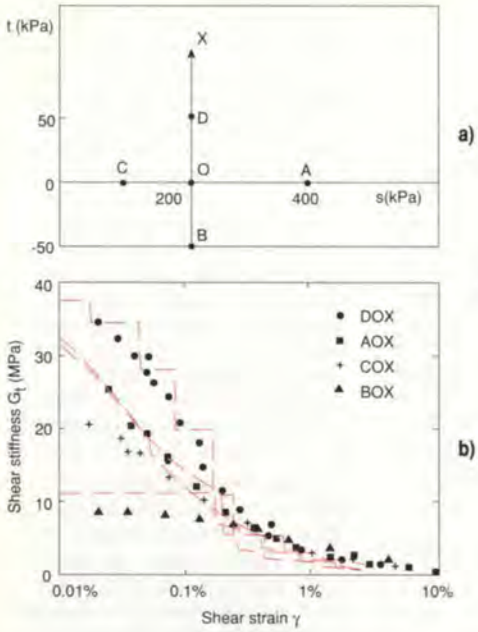
Engineers with a background in plasticity may see in this analogue plastic yield surfaces with axes of stress space. However, the most useful equivalence is to regard the 'room' as *strain* space. The analogue is remarkably useful if the 'man' is taken to represent the point in strain space of a soil element, and each brick a proportion of the element. Movement of a brick represents plastic strain, and elastic strain is given by the difference between the movement of the 'man' and the sum of the movements of the bricks, each weighted by the proportion of the soil it represents. In this view, pure elastic behaviour only occurs on the rare occasions when no bricks are moving, i.e. immediately after a reversal of the strain path. It is assumed that only elastic strains cause stress changes.

The S-shaped curve could be modelled in a step-wise fashion (Fig.4). At very small strains, the material is completely elastic; in the analogue, none of the bricks is moving. As straining proceeds, one brick starts to move, plastic strain begins and the overall stiffness of the soil drops. At a larger strain, another brick starts to move; there is more plasticity and a further drop in stiffness — and so on. The length to each step is a strain, represented by the length of a string in the analogue. The height of the step indicates the proportion of material represented by each brick.

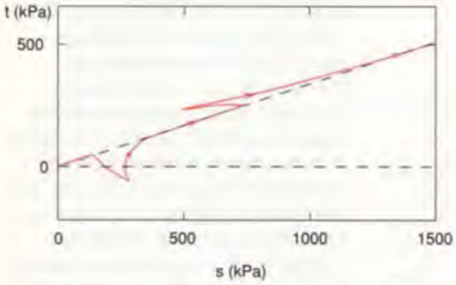
The model has been developed in plane strain for which volumetric strain and shear strain are appropriate axes — the sides of the 'room'. The concept is easily represented in a small program incorporating other features of established soil behaviour theory. In the work described here, 10 'bricks' have been used, representing the S-shaped curve in 10 steps.



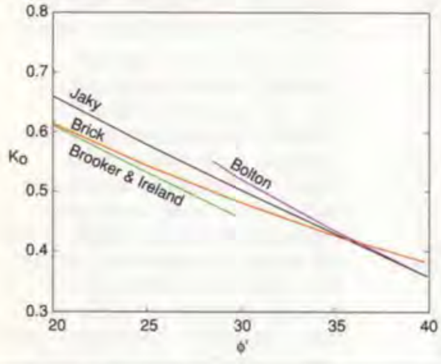
4. The S-shaped curve represented in step-wise fashion.



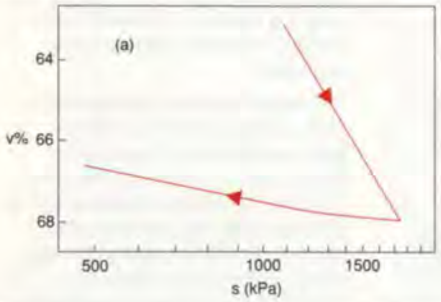
5.
Brick model predictions for Richardson's tests.



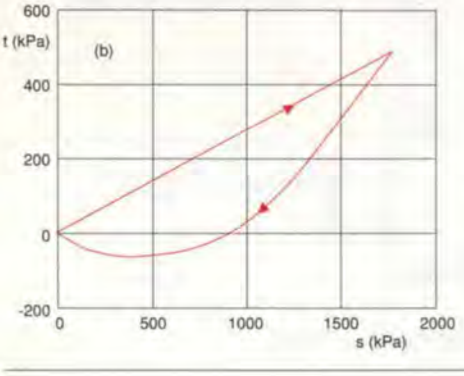
6.
Stress path predicted for 1D consolidation with other excursions.



7.
Brick prediction for K0 of normally consolidated soil compared with other theories.



8.
Brick predictions for 1D consolidation and swelling.



9.
Stress path for 1D consolidation and swelling.

The examples shown will illustrate one way in which this *concept* can be built into a more complete soil model, but there could be many others. The most significant feature is the basic concept that the soil behaves rather like the bricks on strings.

The model was first tested using plane strain stress paths equivalent to Richardson's. Using his data, string lengths and material proportions were chosen to fit path DOX of Fig.2 in a step-wise fashion. With that data and the Brick Concept, the program predicted the stiffness of path DOX and the other paths (Fig.5). Paths AOX and COX appear almost identical in plane strain and BOX has a much lower stiffness. These plots show tangent stiffnesses, for which the curves appear rather bumpy, but this would not be noticeable if secant stiffness were plotted, or when the model is used in a finite element program.

Fig.5 shows that the Brick Concept achieves its main purpose of modelling the effects of stress path changes and reproducing the S-shaped curves which represent the small strain behaviour of clays. However, it has also been found to have a much wider potential.

Additional assumptions

The Brick Model could be used with additional equations describing other features of soil behaviour. A series of assumptions from critical state soil mechanics has been used by Simpson[4] to complete the model and these are briefly listed here.

A consistent set of the values of parameters has been used for all computations involving London Clay, derived mainly from the work of Richardson and Viggiani at City University.

Following previous Cam-clay models, elastic volumetric stiffness is assumed proportional to current mean normal stress. Cam-clay uses two constants to represent this: λ and κ.

A new constant was required for the Brick Model, representing stiffness related to very small elastic strains. Working backwards down the Greek alphabet we come to ι, iota — an appropriate constant to represent very small strain behaviour.

Consolidation and swelling are represented by log-linear equations similar to those of Cam-clay, though they are given new physical interpretation by considering the way in which increased normal stress gives a body the potential for more elastic strain.

Results for normally consolidated soil

Although the Model was initially intended to represent overconsolidated clay, its predictions for normally consolidated soil are surprisingly good. It displays a constant angle of shearing resistance, which is not explicitly a constant of the Model but has been shown to be related to the area under the S-shaped curve. It also predicts the stress paths of undrained tests remarkably well.

For one-dimensional consolidation, the Model always returns to a unique line in stress space, even when disturbed from it by other excursions (Fig.6). The gradient of this line determines K_0 during normal consolidation, for which the model predicts:

$$K_0 = (\sqrt{2} - \sin\phi') / (\sqrt{2} + \sin\phi') \quad ....(1)$$

In Fig.7 this is compared with the well-known equation of Jaky[5]: $K_0 = 1 - \sin\phi'$ and with the results of more recent observations by Brooker and Ireland[6] and Bolton[7]. Equation (1) fits these theories and observations remarkably well, and the Brick Model thus gives an explanation for the value of K_0.

Overconsolidated clays

Houlsby and Wroth[8], Viggiani[9] and others have suggested that stiffness varies linearly with logarithm of overconsolidation ratio, and this assumption has been adopted in the Model. A constant required for this linear equation has been derived from very low strain work by Viggiani. Since the area under the S-shaped curve determines ϕ', the effect of overconsolidation in increasing stiffness must also cause an increase in ϕ'.

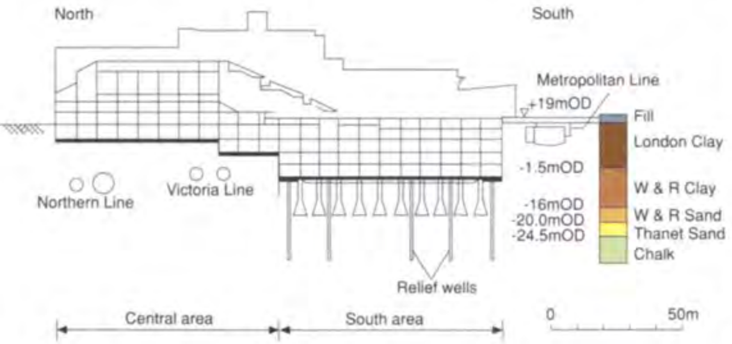
Thus the model automatically gives a higher angle of shearing resistance to an overconsolidated clay than to the same clay in its normally consolidated state.

Fig.8 shows the behaviour of the Model in one-dimensional consolidation and swelling. The consolidation curve is linear in v,ln(s) space, but the swelling line curves slightly. At the beginning of swelling, at the reversal of the strain path, the stiffness is much higher than given by normal assumption of a linear swelling line.

The stress path for 1D consolidation and swelling (Fig.9) has a typical form, returning to the origin at low stress with a gradient given by the inverse of the formula for 1D normal consolidation. Broms[10] suggested that K0 for heavily overconsolidated soils would be the inverse of its value in normal consolidation and this occurs in the model, so K_0 tends to $(\lambda 2 + \sin\phi')/(\lambda 2 - \sin\phi')$. However, because of overconsolidation, the angle of shearing resistance, ϕ', which was constant during normal consolidation, increases during unloading. For the data used here, the S-shaped curve dictates that during normal consolidation the angle of shearing resistance is 22°, of which about 15° is mobilized in 1D consolidation. In the overconsolidated state the peak angle of shearing resistance exceeds 40°, and the maximum value mobilized in 1D swelling exceeds 30°, corresponding to a value of K0 of about 4 — typical for very heavily overconsolidated clay, and in line with the findings of Meyerhof[11] and Mayne and Kulhawy[12].

Use of the Brick Model in a finite element program

The Brick Model is ideal for use in a finite element program such as the Arup Geotechnics program SAFE. At the start of each computation, the soil's geological history is reproduced, considering consolidation from a slurry to maximum overburden and subsequent unloading — thus retracing 100M years of geology in a few seconds on a PC.



10. North-south section through British Library.

The British Library excavation
Fig.10 shows a north-south cross-section through the new British Library. The basement extends through the London Clay and 5m into the clays of the Woolwich and Reading Beds. These deposits have had several important stages in their geological history: (a) deposition, initially as slurry on a sea-bed; (b) consolidation by about 200m of overburden; (c) unloading as the overburden was eroded; (d) recompression by placement of a few metres of fill at ground level; and (e) increase of effective stresses caused by reduction of pore water pressure due to underdrainage in the 19th century. In a finite element analysis using the Brick Model, each geological stage is represented.

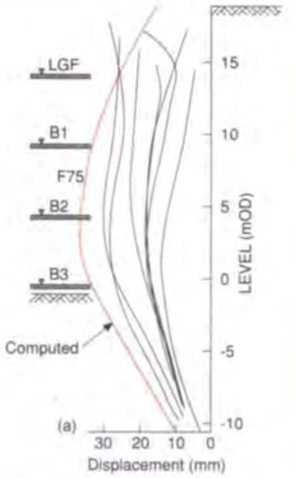
The basement was constructed 'top-down', installing the secant pile retaining walls and load-bearing piles first, so that floor slabs could be installed sequentially as excavation proceeded. Fig.11 shows the computed inward movements of the retaining walls when the basement had reached the B3 level, compared with measurements taken in the walls at various points around the excavation. The computed displacements are slightly greater than the measured values, but the agreement is encouraging, especially since no site-specific small strain data are available for this site.

The computed and measured ground movements for a section through the south wall of the site are shown in Fig.12 at completion of excavation. The two displacement patterns compare well, the computed ones generally being slightly larger.

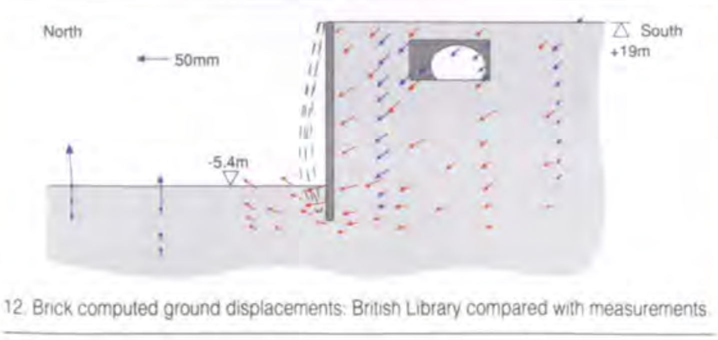
Soft clay in Singapore
Initial testing of the Brick Model suggested that it represents the behaviour of soft clays reasonably well, so it was of interest to carry out a computation for an excavation in the soft clay of Singapore which, like London Clay, is of marine origin and has similar plasticity. This was the basement of a recently completed United Overseas Bank development near the River[13] (Fig.13). The geology varies across the site, with a deep deposit of the soft marine clay around section BB, for which wall displacements were measured. The soft clay overlies much stiffer soils and is split into two layers by a desiccated layer of firm clay and sand.

Field tests suggested that the clays's shear strength was higher than the Model would give for normally consolidated London Clay, so a different set of parameters, used at an earlier stage for London Clay, was adopted.

Comparison of measured and computed displacements (Fig.14) indicates that the Brick Model represents the overall ground behaviour quite well. More detailed measurements of ground movements are not available, but the magnitude and shape of wall movements is well reproduced.



11. Brick computed wall movements (red line) for British Library compared with measurements.

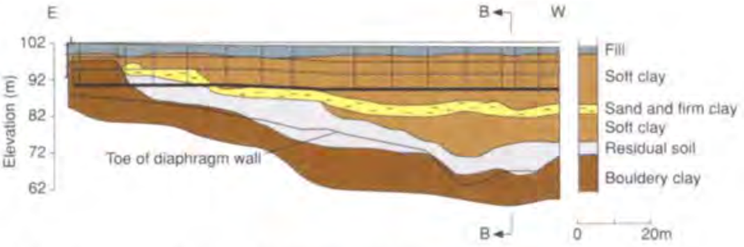


12. Brick computed ground displacements: British Library compared with measurements.

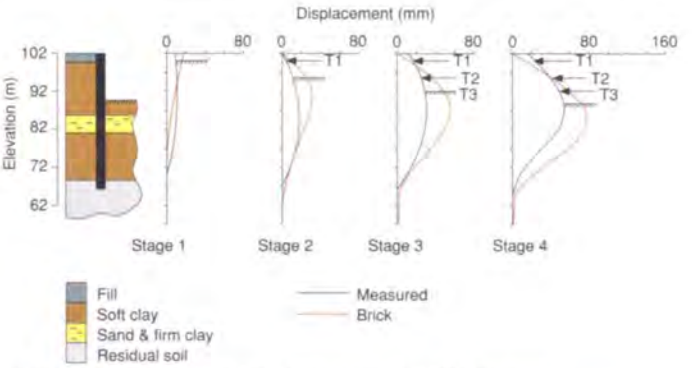
Other applications of the Brick Model

The finite element program is not limited to excavations and the Model is now in use for problems including foundations, tunnels, interpretation of field testing, and so on. It has been successfully applied to back-analysis of pressuremeter tests[14].

The Model can cast light on the behaviour of retaining walls, ralating displacement both to factors of safety (governing the geometry of the walls) and wall stiffness. Its initial purpose was to represent small strain effects in stiff clay, but it seems to reproduce a much wider range of features of the known behaviour of soils. The response to abrupt changes in stress path follow naturally from the analogue and it required fairly minor additions, using well-established theories, to make a more complete model. Failure at constant ϕ' and the value of K_0 for normal consolidation were not explicitly included in the Model but were predicted by it. The same Model appears to be applicable to both stiff and soft clays, and the concept can probably be extended to granular materials as well.



13. Cross-section through the UOB project, Singapore.



14. Measured and computed wall displacements for UOB, Singapore.

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Art of oak: A survey of the frigate *Unicorn*

Peter Ross Ian Sandeman

The *Unicorn* is currently berthed in Victoria Dock, Dundee, opposite the more famous, but much younger, *Discovery* (Fig. 5). She has remained in the water since 1824, when she was built, which makes her the oldest British warship afloat. Indeed, if her condition is taken into account, she is probably the best-preserved historic timber ship in the world.

The history of the ship

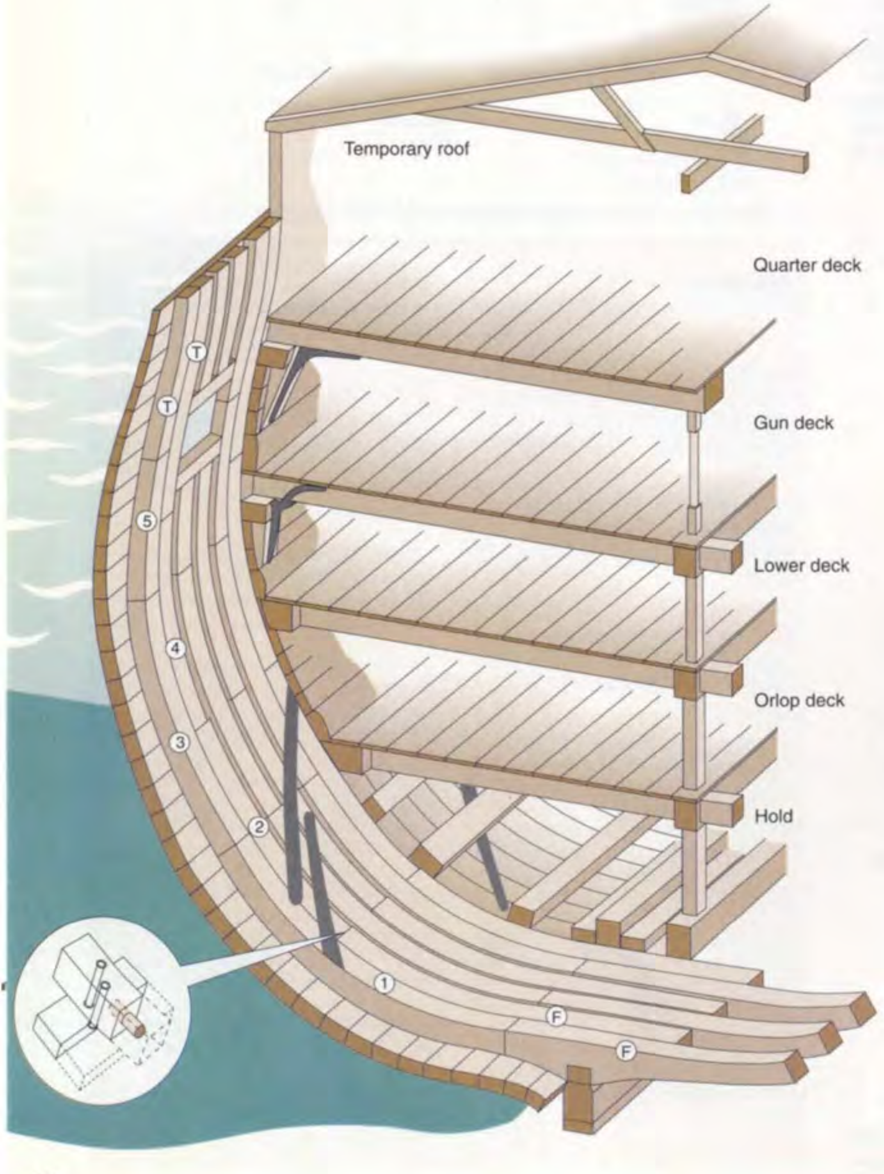
By the beginning of the 19th century the British fleet had been considerably depleted by the long Napoleonic wars with France, and so the Admiralty embarked upon a programme of rebuilding. It took two years to construct the hull of a ship, but only two weeks to rig, arm, provision, and man her. Completed hulls were therefore not rigged but stored 'in ordinary', that is, held in readiness with a temporary pitched roof built over the top deck. Since the launch of the *Unicorn* at Chatham coincided with an outbreak of peace, she has remained 'in ordinary' to this day, her temporary roof the only extant example. Used at various times for training purposes, she was towed to Dundee in 1874, and has remained there ever since. This relatively protected existence, with little racking of the frame at sea, plus the cold waters of the Tay estuary and the copper sheathing to the hull, have all contributed to the incredible longevity of the ship, now some 168 years old.

She is now 'retired' from the Navy and owned by the Unicorn Preservation Society, who have opened her to the public. In 1991 they decided that a structural survey should be carried out 'to determine the condition of the ship, its ability to be moved and the works necessary to ensure its future'. The commission was awarded to Ove Arup & Partners, together with their consulting marine surveyor.

The construction of the wooden ship

The earliest ships were of clinker construction: overlapping planks fastened edge-to-edge to create the hull, with frames then fitted inside the built shape. Although this technique lasted for some 3000 years, it was eventually abandoned as it limited the maximum size of ship that could be built. By the beginning of the 16th century, when Henry VIII began building warships in earnest, the sequence of construction had been reversed. A 'rib-cage' of frames sprang from the 'backbone' of the keel, and was subsequently sheathed with edge-butted planks, fastened to the frames, but not to each other (Fig. 1). This system of framing and planking was paramount for 300 years, being used for such ships as the *Mary Rose* (1509) and *Victory* (1765). The *Unicorn* is one of the last examples of the system, and even so the then Surveyor of the Navy, Robert Seppings, introduced some modifications to the traditional details.

1. Cutaway at midship section showing hull construction.



2. Gun deck with messing arrangements.

4. Some frame members were soaked in brine as an aid to preservation and marked 'SALT'.

5. Left: The *Unicorn* berthed in Victoria Dock, Dundee. The *Discovery* can be seen in the background.

6. Below: The Captain's cabin.

The ship has an overall length of 150ft (the Navy remains stubbornly 'Imperial') with an unladen displacement of around 750 tons. All the main frame members are heartwood oak, with some softwood in the decks; some of the frame members were soaked in brine as an aid to preservation, and marked 'SALT' (Fig. 4). The planking below the water line is probably elm.

Each frame is actually made up of paired members (Fig. 1). Floor timbers (F) are fitted over the keel, followed by the futtocks (1 to 5), and finishing with the top timbers (T). The joints are simple butts, with a dowel or 'coak' fitted. The obvious bending weakness of these joints is compensated by the staggered arrangement of the futtocks, and by the bridging action both of the planking on the outside face, and the stringers on the inside face.

All the fasteners are of metal — indeed but for them the whole assembly would fall to pieces. The planking is fixed to the frames with bolts of copper for durability, and to avoid bi-metallic corrosion with the copper sheathing. Despite their name the bolts are fitted in the manner of a rivet, with the end clenched over a washer by hammering. Internal bolts are of iron.

3. Left:
Lower deck near
the stern showing
frame and stringers.

The condition of the frame

As the survey progressed, it became clear that all of the main frames, and indeed most of the secondary timbers, were original, and that the majority were in good condition. However, a few of the floor timbers showed evidence of wet rot, both on the surface and more significantly within the depth of the timber. Although overall the condition was excellent, the *Unicorn* did not have the secret of eternal youth.

The wet rot, especially while the ship is still in the water, is a very real problem, and tests are currently under way of methods of treatment using boron, under the direction of the Dundee Institute of Technology. Although the preliminary results, in terms of penetration of the timber, seem encouraging, further work is needed to establish the long-term effects of boron on timber.

Conservation strategy

It will be possible for the ship to remain afloat for some years before the incidence of rot becomes critical, but Arups' recommendation was that the vessel be taken out of the water and over-roofed. This could be achieved if permission were granted to use the adjacent dry dock on a permanent basis. The ship could never be refloated, and there would still be a long period of risk, but eventually the timbers would dry out sufficiently to preclude further rot. While some of the timbers would not be in perfect condition, it would be possible to support the hull in such a way as to maximize the retention of original material.

The conservation of the *Unicorn* is important not only because of the survival of so much of the original construction, but because she was one of the last of the 'wooden walls' to be built. Already the experimental installation of steam engines in hulls had been made, linked to paddle wheels.

Two further developments — the iron hull, and screw propulsion — culminated in the launch only 19 years later of Brunel's *Great Britain*, the first ocean-going vessel to be screw-driven and built entirely of iron.

The wooden ship sailed into a glorious sunset with the development of the 'clippers' such as the *Cutty Sark* (1860). They actually had composite hulls — iron frame, hardwood planking — but by the turn of the century iron, as in other forms of construction, had replaced timber throughout Europe for ships of all but modest size. The most enduring naval image, however, is still that of a wooden ship under sail. The *Unicorn* is a unique survivor from that period.

Credits
Owner:
The Unicorn Preservation Society
Client:
The Dundee Partnership
Structural engineer:
Ove Arup & Partners
Marine surveyor:
James Anderson
Photos:
Peter Ross
Illustration:
Denis Kirtley

7. The quarter-deck with temporary roof.

RIBA Royal Gold Medal Speech 1992

Peter Rice

Peter Rice, who died on 25 October, received the Royal Institute of British Architects Royal Gold Medal for Architecture on 29 June 1992. He was only the third engineer to be so honoured, after Pier Luigi Nervi and Sir Ove Arup, since the award was instituted by Queen Victoria in 1848. He was also the third member of Arups to receive the Medal, following Sir Ove in 1966 and Sir Philip Dowson in 1981. The transcript of Peter Rice's acceptance speech has been edited slightly for publication here; edited versions of the speech, the opening comments by Richard MacCormac, RIBA President, an introductory tribute by Renzo Piano, and a response by Richard Rogers, were also published in RIBA Journal, September 1992.

1. Peter Rice at the Sydney Opera House site in the mid-'60s. Having worked in the London office on the building for several years he joined the resident engineering team in early 1963.

2. The Opera House under construction, photographed by Ove Arup.

There is a book of essays by W.H.Auden called *The Dyer's Hand*, and in that book of essays he has one which he calls 'The Joker in the Pack', in which he analyzes the rôle of Iago in *Othello*.

Iago, if you remember, destroys the love of Othello and Desdemona by rational argument, by applying reason all the way through to every act which, particularly, Desdemona undertakes. And in the eyes of many, the Iago rôle is the rôle given to the engineer in modern life and in modern architecture: of actually reducing by reason, to destroy or to undermine the kind of unreasonable and soaring ideas that architects may have.

But it doesn't have to be like that because, in fact, the engineer has a rôle; and one of the things I want to try and explain or talk a bit about tonight is what an engineer is and what an engineer does, because even my own children ask me, 'What does an engineer do? You just make the thing stand up, don't you?'

And in reality I think the rôle and position of engineers is not really understood at all in our modern society. They are perceived, as I said earlier, as rational men who have always to reduce everything to the point where they can be sure of justifying it by reason.

But there is a way around this. When I was young, starting out in my career, I wasn't quite sure if I would become an engineer or not; I ended up in the profession largely by accident, chosen for me by my father. When I grew up in rural Ireland the word 'engineer' had no meaning to me, any more than the word 'architect'. I didn't have any kind of cultural base at all — it was all literary, not in the tactile or physical arts. I discovered when I started looking at the work of engineers that the work I most liked was made by engineers who were exploring things: people like the great Victorian engineers who were drawing enjoyment out of exploring these new materials, this new industry that had been created — people like Maillart or Nervi exploring concrete. I realised that even when you start looking, say, at Gothic cathedrals, the best and finest were the ones which were done by people who were actually trying to find out how to build them. These were the ones where they injected the optimism and the joy and the enjoyment gained from what they were doing.

I realised that it was an essential ingredient in the work of engineering to be exploring.

If you like to categorize, or find the difference between engineering and architecture, I would say that the architect works in a subjective way whereas the engineer is working in an objective way. But this objective world of the engineer contains many elements that you might not actually expect it to contain. It contains elements, of course, of exploring materials, which I will talk a little bit about later, but it also includes understanding what I would call observable facts.

For instance, one of the things which interests me a lot at the moment is the difference between real and virtual surfaces: how as an engineer, as a structural engineer, one can change and destroy a space by introducing a virtual surface into it which is made by the structure but which has in a sense got no continuity. These kinds of observable facts all become part of this objective world which an engineer is attempting to explore.

An architect, essentially, is responding subjectively to what his work can do. He is taking the context of a place and he is saying 'What do I feel should be put into this place?', whereas an engineer is taking materials, is taking some of this subjective information, and is working with it to invent rather than to create. Renzo used the word 'creative', but if you think about these problems in French, there is a clear distinction between the concept of creation and the concept of invention.

It is this difference in concept which I think identifies the difference between the architect and the engineer. And it is this difference which identifies the difference between the subjective world and the objective world. I think that's why there isn't really, and doesn't need to be, any overlap of activity. Both are needed to get the best out of any situation.

I think that in trying to understand this inventiveness which the engineer can bring to what he is doing, one has to recognize that he is working with and working within the framework of information which he would generally call — as I've said before — objective.

At its simplest, it is easiest to see this when we are thinking of materials. I am particularly interested in exploring materials. And generally in any project I do I try — I make this almost a requirement of my work — and find something within it which provides me with an opportunity to explore. I feel that in exploration you find the enjoyment and the originality and the simplicity which, because you don't know what the outcome will be, are a necessary part of communicating with the public.

One of the things that interests me very much as an engineer working in architecture is the whole problem of the alienation of the public at large from the current architectural situation. Myself, I believe this is due not to the problems of style and other things which many of our critics talk about, but to the rôle of industry.

I think what has happened is that the actual process of making architecture has become dominated by industry, and people cannot any longer see the connection between what is built and the people who have built it. If you go back to the buildings and the things which we like from the past, one continuous factor, one element, is constant in all of them, and that is that you can see the evidence left by the people who made it. Whether it be a Gothic cathedral or a Victorian structure, there is some element within it which leaves behind a feeling that people themselves were involved.

It is this, what the French would call *place de la main* — the evidence of the participation of people in the process — which I think is the key ingredient in enabling us to keep contact with the public, to keep people so that they feel comfortable with and don't feel alienated

3. Centre Pompidou.

by the products of our industry. I think it behoves us — and particularly the engineers because we're the ones who can speak the language of industry, the ones who can challenge industry and challenge its assumptions — to tackle it and to break this dominance and to try and find ways of actually communicating the real elements and the real nature of things.

Exploring materials and exploring the use of materials, and inventing through this exploration and using the nature of the materials themselves, stimulates and creates this contact. The natural characteristics of materials as a design stimulus is the ingredient which provides the best way of providing the contact between the public and the buildings that we build.

At the time of the Centre Pompidou I had one very gratifying moment. We were building the steel structure and I was very concerned that the scale of the building and the nature and face of it would be very intimidating. Particularly when people are looking at things, they carry with them prior prejudice. When you build a steel building all the other steel buildings that people have seen become part of the way they react to what they're looking at.

It was then that I principally conceived the idea of introducing the cast steel because I wanted to break some of these prior prejudices and produce something which would be unexpected, and in being unexpected would challenge people to look at it, and in the process of challenging them to look at it would actually make them think: 'What is it? What is it that I'm looking at?'

One day, I suppose nine months after the building was complete, I was visiting it and I saw an old lady, just like the old ladies who my mother knew in Ireland, dressed in black, sitting on the fourth floor with her hand on the gerberette just looking at it. The gerberette was the great big cast bracket which we put round the columns (there was a great trial at the time we were trying to get it approved). I watched her for about an hour, just sitting, quietly, stroking the side of the gerberette. And I thought that if somehow, by introducing elements like that, we can make people who would normally be alienated by things feel comfortable, it proved to me that in a way the thing that matters is that we introduce elements and materials into buildings in a way which reflects their real nature. And it's this relationship between the real nature of things and the real nature of the element itself which I think is the nakedness by which we can communicate with the public at large.

4. Glass façade at The City of Science and Industry, La Villette, Paris: One of Peter Rice's projects from the early '80s. (Photo: Martin Charles)

I would like to illustrate how this actually works. I would like to take you through a recent project I've done which is the Seville stone arches[1] where we were seeking to examine, to explore, how you would use stone in the modern context. Lots of things have changed recently in stone manufacture and our capacity to cut and make stone. Also our current computer technology enables us to explore and examine things which we wouldn't have been able to explore 10 years ago, because we didn't have the right computer logic and frameworks for doing it.

Now the thing about stone is that recently there has been an enormous improvement in the accuracy and way in which you can cut and make stone units, stimulated largely by the large façades which are very much part of the cladding industry, and you can cut stone to accuracies of 0.5mm.

So I realised that it should be possible to assemble stone in such a way that the previous way in which stone was thought of could be bypassed. And I conceived the idea that we could prefabricate stone sub-assemblies in a factory and then assemble them almost as though they were made of precast concrete, but with dry joints. These dry joints then protect the stone, for stone as a material is really very like glass. I had realised at the time that we were making the glass façades at La Villette that the kind of techniques of using shock-absorbers and prestress springs in that project would actually be adaptable to designing in stone. The stone arches at Seville are based on the premise that you can make pieces extremely accurately and then by dry-jointing them you can protect them against cracking and protect them against the unacceptable stress levels that might arise. And by using that we could actually rediscover the structural use of stone and hopefully get back to a natural and real way of using what is, after all, the most fundamental and basic material on earth.

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(1) *See also* PETER RICE & ALISTAIR LENCZNER. Pabellon del Futuro, Expo '92, Seville. *The Arup Journal, 27*(3), pp.20-23, 1992.

▲ 5. Palaçio de Ajuda, Lisbon.
(Photo: Alistair Lenczner)

◀ 6.
Peter Rice (back to camera) inspects prototype of stone unit for the Future Pavilion façade at the stonemason's workshop, July 1991. (Photo: Bruce Danziger)

It was quite strange. Obviously, when you want to do anything a bit new everyone runs for cover. But in the end the stone industry were very positive about it. And every single thing that we postulated came good.

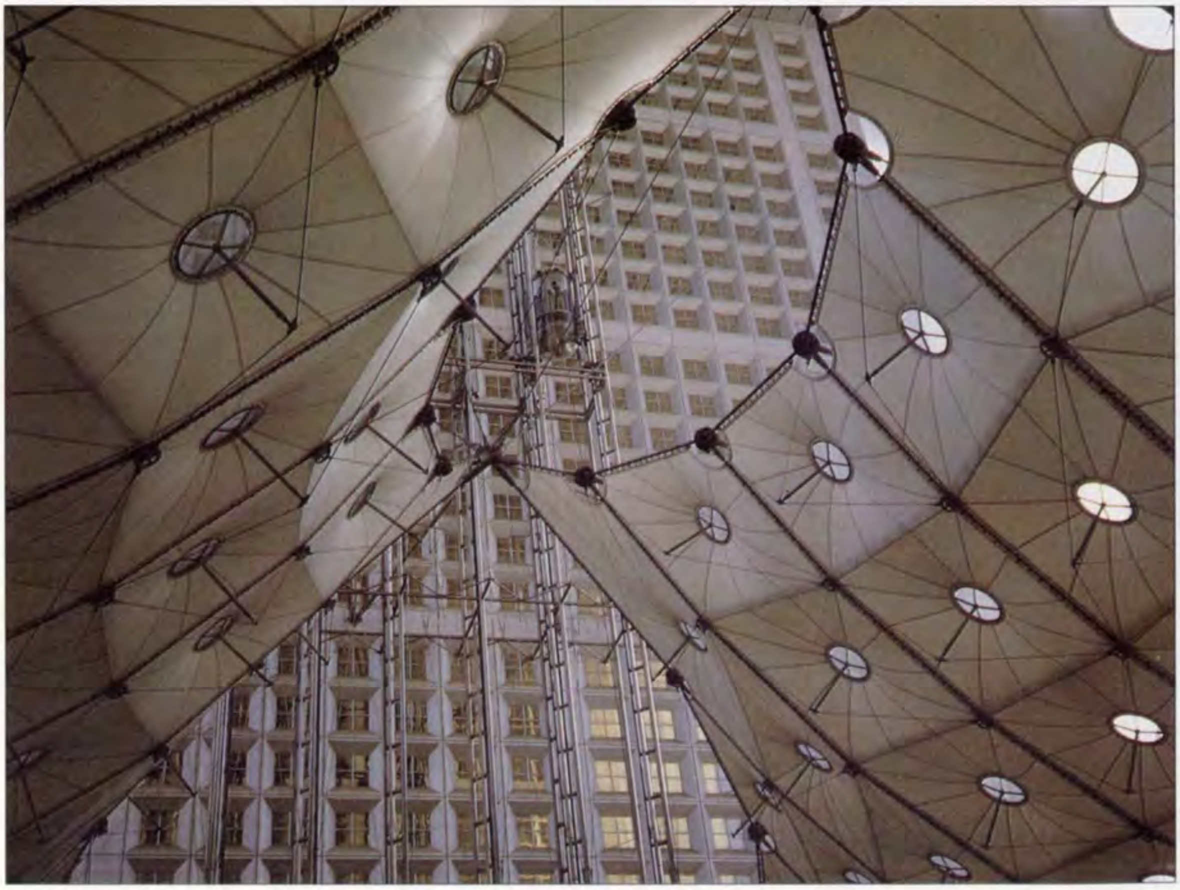
Once you start out on something like this, you follow your nose. The invention becomes inevitable. You look at what you've got and the next phase of it becomes obvious and bit-by-bit the whole process has a direct inevitability about it which is not at all subjective or even arbitrary.

The original design was done with Oriel Bohigas and David Mackay from Barcelona, and they came to me one day and said: 'We've been invited to do the Future Pavilion and the client wants something spectacular'. Now that's the kind of challenge that a fellow like me can't refuse. About a month or six weeks before I'd been to a place in Lisbon called the Palaçio de Ajuda and it was a building which had been in construction at the time Napoleon had invaded Portugal way back in whenever he was around. The building was half complete and there was one complete wall which was built, but the building behind it had never been built. It was quite big and as I stood and looked at it I thought 'Well, if that thing can stand there for 100 years I should be able to design something like that'.

So I went back and we were asked by David and Oriel to come forward with an idea for the Pavilion. I proposed for this long linear site this wall, originally designed a bit like the one in Portugal, but it gradually developed into the series of stone arches, where the stone is used entirely structurally.

There were two or three reasons for that: stone technology is at its most advanced in Spain; Spain is currently the home of stone technology even more than Italy, and it seemed quite appropriate that we should attempt to do something like that for a thing called a Pavilion of the Future in Seville. The façade is about 290m long and it's 40m high and it's made up of stone pieces which are 200mm x 200mm. There is a remarkable thing about stone, it can be about three or four times as strong as concrete.

The stone in fact in this case is granite from Galicia in north-western Spain. If you go up to Galicia you find that, all over the place, they have these standard posts used for holding their vines up or as gateposts which are 200mm by 200mm and about 1.3m high. I decided that if we were going to build in stone



◀ 7.
Underside view of the 'Nuages' canopy structure (within the 'Grande Arche', La Défense, Paris) for which Peter Rice was responsible.

8. ▶
Kansai Airport Terminal, one of the last major projects on which Peter Rice worked, under construction on the artificial island at Osaka, Japan, November 1992. (Photo: Stuart Cowperthwaite)

that was the piece of stone we should use. So we assembled that type of piece of stone into sub-units, 0.8m x 0.8m, using this quality of accuracy that we felt we could get in the cutting process.

The cut and shape of the various elements was no problem for the stone industry. In fact, they were a little bit disappointed that we didn't ask them for anything more challenging than we did. They felt that we'd underestimated their capacity. We had different types of units, all made up of sub-assemblies; everywhere there is a change in section there's an epoxy joint with a dowel in it. We developed a computer program which represented the opening and closing of the joints in extreme conditions, such as earthquake or extreme wind and the like.

I wanted not just to make the pieces as you would traditionally think of stone, but to actually identify what I would call a current modern inevitability of the technology we have today. It's not just using stone as it might have been used, say 100 years ago, and showing that it can still work. It's actively going out and exploring what stone can become today. And that's something that also interests me very much, the idea that working as a technologist you are actually working with the technology of today and that what you do could not possible have been done, say 10 or 20 years before, as I think is probably the case in this particular structure.

As I said a moment ago, when you start out on this process you make certain critical decisions at the beginning, but then it's a question of following your nose; the material itself tells you what it wants to do. You don't actually have to think too much about what's required because the nature and character and physical properties of the material become the motive force for just about all your decisions.

The most difficult part of any innovative new project is persuading the contractor to build it. The contractors feel they are personally taking the risk — and I understand that — for some hairbrained idea of somebody else's. Particularly as this was the first time I had worked in Spain, I didn't really have any kind of track record with the Spanish, so they were very sceptical and they thought that maybe when things got rough I'd do a bunk. So I just kept saying 'Ove Arup, Ove Arup, biggest in the world' — all that kind of thing — just to reassure them, but they weren't entirely convinced.

However, bit by bit, they launched themselves. They had a couple of very good engineers that were working on it, and they launched themselves, and of course once they were launched they were caught up on their own pride and we were able to proceed. We had a few rough rides, as you might say, particularly with one unit which cracked the first time they put it up, but that was because they carefully chose not to listen to anything we told them so that it was only really when things went wrong they came back and said 'Well, what was it you were saying the last time?'. We convinced them to do it the way we wanted them to. Once they got going it went up very, very well and very easily, and with great precision.

The stability of the whole structure is guaranteed by two things — guaranteed by itself in a sense. It's not a prestressed stone arch; there is a certain amount of weight applied to some of the arches, which is the weight of the roof system which was supported from behind.

But there are some of them which have little or no weight on them and it's only really the self-weight of the stone system itself which is holding up this almost 40m high façade. Its out-of-plane depth and thereby stability is provided by elements providing the action of vertical cantilevers with the steel members behind and the stone façade in front.

All of that is possible because this structure works not as a structure where you analyze stress and strain and all that, but where you analyze the geometry. And it's the geometrical change which must take place before any kind of collapse can be precipitated which guarantees the safety of the whole thing.

So that what we have done is analyze the whole system with all these joints opening up and closing, and the geometrical change which that induces or that requires is more than sufficient to bring the whole system back into equilibrium, even though it can be under some very non-symmetrical and different types of loading.

It's this combination, if you like, of current thinking and software, much of which we adapt and write ourselves, stimulated by the requirements of the project — this mixture of that and the advances in material technology itself and cutting and manufacturing technology — which I think represents the contribution and the way in which we can get back to introducing materials and allowing materials to exist in our buildings in their fundamental, authentic form. I often think, for instance, that when the critics and people who don't like modern architecture criticise it, they are criticising what I was saying before — they are criticising the separation between the process and the product.

By going backwards into the materials, and actually using the materials as authentically as they can be used, we will recover some of this lost ground, and that's probably the contribution that the engineer can make to architecture and to the art of building because it doesn't have to be a reducing by reason, forever saying 'Well, that's not possible, all you can do is what I'm telling you can do'. You can actually get yourself into a situation where you can go off and you can fight with the architects sometimes.

So, if I have a philosophy, if I have a belief, it is that the contribution that we can make and the contribution that we should make is not to be quasi-architects; people often call me an 'architectural engineer', but that's a load of rubbish — I'm an engineer, plain and simple. I think of myself as contributing in an inventive framework based on objective information, and this objective information, as I've said, can come from all sorts of different sources. It doesn't have to be the kind of thing you first think of as objective information. I find anything that's observable and that you can see and understand becomes objective in itself. And I think that's where we have to work, that's where our contribution is. It is by being inventive in that kind of world that we can contribute and help, I believe, architecture recover some of its rôle in society.

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COMMENT

Bob Emmerson

This issue of Arup Focus tells of the growth of our offices in the United States and the work they are doing. I would like to say something here about what I believe to be the reasons for our success in a country noted for its competitive climate and during a period for half of which the American economy has been in poor shape.

We brought to America what we call building engineering: integrated multidisciplinary design by integrated multidisciplinary project teams. And, equally importantly, we brought a different - or, at any rate, an unusual - attitude towards the projects and the owners and architects with whom we work. It is an attitude more interventionist, seeking dialogue and collaboration, anxious to be involved in developing all aspects of the design from the very earliest days of the project; an attitude that seeks the solution best for the project even though the search may be a difficult one. In short, the Arup attitude.

We are helped by many things. Loyal owners and architects are high on the list, and their generous recommendations have been of great value. We are helped also by the support we get from colleagues in various branches of the Arup family around the world, who share with us their experience and sometimes even their staff. And we are helped by the breadth of Arups' skills, several of which we have been able to bring to America: transportation and traffic planning, communications and information technology, industrial engineering, and a branch of Arup Acoustics in Los Angeles.

The 'American Experience' is also benefiting all 50 offices in other parts of the world. Not only the practical experience of American construction and management techniques, but also their 'can do' attitude of mind. Our American offices are currently collaborating with local Arup offices on projects in England, Germany, Abu Dhabi, Saudi Arabia, Singapore, Malaysia and Japan.

Finally, our continuing success in the United States would not be possible without the dedication of our staff there. Every time I visit America I am impressed by their commitment, their energy and their enthusiasm as part of the Arup family.

Bob Emmerson is Chairman of Arups' American practice.

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AWARDS

Many projects received awards during the past three months. Among them were:

ISE Structural Awards

The Institution of Structural Engineers gave a Structural Award to Ove Arup & Partners for their work on the British Pavilion and Pavilion of the Future, Seville, and a commendation for their work on Central Plaza, Hong Kong.

Silver Jubilee Cup Award of The Royal Town Planning Institute for 1992

This award, which aims 'to throw a public spotlight on the positive achievements of the town planning profession', was made to the Broadgate development, for which Arup Associates were masterplanners. The judges described it as representing 'a model of high density for city centre redevelopment'.

(Right): Chapel at Fitzwilliam College Cambridge (architect: MacCormac Jamieson Pritchard), one of four Arup projects to receive Civic Trust Awards. The others were Stansted Airport Terminal, Royal Insurance House, Peterborough, and Avenue de Chartres, Chichester.

(Right): Usine de L'Oreal, at Aulnay-sous-Bois (architect: Denis Valode and Jean Pistre) was awarded Prix de l'Equerre d'Argent by *Le Moniteur*.

HONG KONG AIRPORT RAILWAY

Two new lines of the Mass Transit Railway will link Hong Kong to the island of Lantau and the new airport at Chek Lap Kok. Ove Arup & Partners Hong Kong competed for and won commissions as civil and structural engineers for four major new stations on these lines, and the tunnels and viaducts associated with them.

The Airport Express Line will run between the airport terminal building (for which Arups are concept and specialist structural engineers), stopping at Tsing Yi, Kowloon and Hong Kong Central. The Lantau Line follows the same route, with intermediate stations and will provide interchange facilities with the existing Tsuen Wan line at Lai King and the Island Line at Hong Kong Central. On Lantau the terminal is at Tung Chung, a new town adjoining the airport. Arups' commissions are for the stations at Hong Kong, Kowloon, Tsing Yi and Tung Chung.

The Mass Transit Railway Corporation in partnership with the private sector has a record of successful property development, and is taking full advantage of the wider commercial opportunities offered by the new stations. Most will have major road interchange facilities along with shops, hotels, flats and offices in multi-level podiums and high-rise buildings above or adjacent to the stations.

MTRC: Lantau & Airport Railway Route Map

Hong Kong Station, for which Arup Associates and Rocco Design Partners are the architects, will be located on a 3.2ha prestigious site on newly reclaimed land in Hong Kong Central, in front of Exchange Square, and connected by a subway to Central Station, both earlier Arup projects. The station itself will include three underground levels

and two levels of podium with five office and hotel towers up to 46 storeys high.

Kowloon Station, designed by Terry Farrell & Co with Ho & Partners, covers 14ha on newly reclaimed land, and will have two underground and three podium levels. Also included are 12 34-storey office and hotel towers and 26 high-rise residential blocks.

Tsing Yi Station (architect: Wong Tung & Partners) is an elevated station within a seven storey major shopping and town centre podium covering 5.4ha. Above the podium will be 12 residential towers.

Tung Chung terminus is a two-level underground station with an above ground concourse integrated with adjacent commercial and residential developments covering 22.5ha. The architectural design is by MTRC with Arups acting as team leader to co-ordinate the work of all consultants.

Although the buildings will be the most conspicuous aspects of these stations, the civil engineering works - viaducts, tunnels, subways - represent a major part of Arups' commissions. The railway is a key element in Hong Kong's 'Airport Core Projects' and its infrastructure programme. Design work is now under way by Arups Hong Kong with additional staff from their offices in Taiwan, Australia and the UK. Tenders will be invited later this year and construction starts early in 1994. Completion is planned for 1997.

CHAIRMAN'S REPORT

John Martin

In November I presented my Annual Report to the Partnership and I am pleased to have the opportunity now to publish extracts which may be of interest to our clients and other friends.

The recession has greatly increased international activity in the construction industry. This has been true for us: international competition has affected us everywhere we practise. Our overseas work has grown and, increasingly, we form or join teams to make design/construct bids. It has been an exciting and a demanding year, but the width of our business and the range of our skills have enabled us to cope remarkably well.

Our work in continental **Europe** has grown, particularly in Germany, where we have projects in Berlin, Koln, Dresden, Dusseldorf, Frankfurt, Leipzig and Stuttgart. In France we have a variety of technically demanding jobs, including La Tour Sans Fins, which will be the tallest building in Europe. Last year we completed several notable projects in Spain, amongst them the Barcelona Tower, the Thyssen Art Gallery in Madrid and the UK Pavilion and the 'Pavilion of the Future' for Expo '92 in Seville.

Our **Hong Kong** office has been the focus of much activity, with projects and possibilities not only in Hong Kong, but also in mainland China and parts of South-East Asia. Among major developments of particular importance are the new Hong Kong Airport and Metro stations and the Bangkok Elevated Transport System.

Our work in **Japan** and with Japanese companies has been valuable. The relationships we have built and the experience we have gained should be a good investment. Particularly noteworthy are the Kansai airport, now under construction, the Toyota factory at Derby, with 230 000 m^2 of production space completed to time and budget this year, and Bracken House, a speculative office development for Obayashi now leased to the Industrial Bank of Japan, and awarded the British Construction Industry Supreme Award.

In **Building Engineering**, apart from the increase in our overseas activities, we have been helped through this difficult year by the Glaxo project at Stevenage, for which we are the prime agents. It has a construction value of £500M and at the peak 210 of our staff were engaged on it. The experience gained on this project will have a considerable influence on our working methods in the future.

Industrial Engineering has steadily grown in scope and in the geographical spread of its work. The Toyota factory at Derby is being followed by another in Turkey. Work has continued in Germany and projects have been gained in Hungary and in Russia.

Our **Civil Engineering** activities have become increasingly important to us. We have obtained more work in environmental services, transportation, highways and bridges, and a reasonable flow of work in infrastructure and geotechnics. During the year some 20 of our staff have worked as part of the British Rail team assessing the Channel Tunnel rail link route options so that a recommendation can be made to Government. It remains to be seen what our future involvement might be.

We increasingly find ourselves in a position to make a fundamental contribution on planning and development matters, and there is scope for building on our skills in environmental engineering and science, acoustics, planning and economics. These, combined with our longer established skills in civil engineering and geotechnics, have brought us a good deal of interesting and valuable work, including environmental assessments and appraisals, land reclamation, waste disposal and site improvement schemes.

Barcelona Tower
Architect: Sir Norman Foster & Partners

There is talk of change to meet changing needs. Certainly the nature of the work available is changing, which can be stimulating, but also the environment in which we work is getting tougher, more competitive and more litigious. This means that we are having to change our habits, which is probably no bad thing. But we must take care that we do not lose sight of our aims; we are driven by the quest for excellence in our work and in our dealings with our own and other people. We should remember, too, that although we will always seek to diversify in our activities, because it is in our nature to explore the fields adjoining our own, we must not neglect our roots. We are seen to stand for excellence in design, and I believe we must continue to see that this underlies all we do.

Torgauer Strasse, Leipzig, a 4.5km urban highway and bridge project.

PROJECT NEWS

Work commenced last year on the £160M **NEWCASTLE QUAYSIDE DEVELOPMENT** which will regenerate a 20 acre steeply-sided site on the banks of the River Tyne. The Tyne and Wear Development Corporation are funding the project and OAP Newcastle are prime agents and engineers for the infrastructure and car parks.

The Christmas issues of the **WESTERN MORNING NEWS** were launched from the paper's new **HEADQUARTERS** in Plymouth. OAP were engineers for this £15M ship-shape building. Architect: Nicholas Grimshaw & Partners.

OAP were engineers for the fit out of **EMBANKMENT PLACE** which started in January 1992. This has now been completed and Coopers & Lybrand have moved in 3500 people. The communications design, also an OAP project, reaches a level of quality and economic efficiency, and the installation is now fully operational.

Work on site is now progressing on **CONGREXPO**, Lille, a project comprising a 5000 seat rock concert hall, a 20 000m^2 conference centre and a 20 000m^2 exhibition hall, adjacent to the new TGV station development. OAP are structural and services engineers for the project. Architect: Rem Koolhaas.

On 25 November 1992 the Turkish Prime Minister opened 92km of the **TRANS EUROPEAN MOTORWAY** from Selimpasa to Luleburgaz, west of Istanbul, together with five link roads connecting the motorway to the existing Edirne to Istanbul road. OAP Coventry Highways Group are designers for this design and construct contract, and also for the 150km long Edirne-Kinali Motorway. Construction of the remaining section to Edirne is now in progress.

Arups have completed two stages of preliminary engineering for a **CONCRETE GRAVITY SUBSTRUCTURE (CGS)** for the **BRITANNIA** field. This is the first time a joint field operatorship has been considered in the North Sea.

PORT WAKEFIELD, the £150M, 350 acre railfreight terminal and freight village has been granted outline planning permission. OAP Leeds, working with Arup Urban Design, Arup Environmental, Arup Transportation and the Manchester office, drew up the masterplan and took this project through a four week Public Inquiry.

PARTNERSHIP NEWS

MARGARET LAW *of Arup R&D Fire Engineering received the MBE in the New Year Honours List.*

DEREK SUGDEN *ex-Chairman of Arup Associates and current consultant with Arup Acoustics, has succeeded the Lord Bancroft as Chairman of The Building Centre Trust.*

The Institution of Structural Engineers recently made a Service Award to ***GRIFF SAGE,*** *OAP Cardiff, in recognition of his 27 years' service to the Welsh Branch throughout the period 1963-1990.*

DAVID LOOSEMORE *of OAP Civil Engineering Infrastructure group is one of the 'conciliators' listed by the Institution of Civil Engineers in connection with their seminar 'Conciliation and the ICE Conditions of Contract - A New Stage in Dispute Resolution'.*

OAP BRISTOL OFFICE *received a Business Energy Award 1992 for their own office building. The citation stated that this conversion of an old warehouse was a reflection of Arups' commitment to Bristol.*

The ***OVE ARUP FOUNDATION PRIZE,*** *one of the 1992 Partnership Awards, reflects Ove Arup's own commitment to the advancement of education associated with the built environment. This year's prize, 'Creativity in Engineering Design for the Built Environment', has been awarded to Hilary Smith of the Department of Civil Engineering, University of Leeds.*

Ove Arup & Partners are among the winners of the ***BCB CONSULTANT OF THE YEAR AWARD 1992****. This is in recognition of outstanding contributions made overseas both to the country where the projects are undertaken and to Britain's invisible earnings.*

Ove Arup & Partners were one of eight featured 'case study' companies in a report ***INNOVATION - THE BEST PRACTICE****, compiled by a joint CBI/DTi task force which aims to encourage innovation throughout British industry.*

PETER BRESSINGTON *and* ***MARTIN KEALY****, both of AR&D Fire Engineering, were involved in a BBC TV documentary 'Tomorrow's World', which examined atrium fire suppression systems. They directed fire tests at the Hammersmith Ark and Fire Services College at Morton-in-the Marsh.*

The Ove Arup Partnership and the British Council were sponsors of ***PROJECT IMAGINATION MOSCOW****: a series of workshops involving architectural students and architects, held in Moscow in November. The participants included Chris McCarthy of OAP and Mick Brundle of Arup Associates.*

The Ove Arup Partnership has contributed to a charitable trust for Construction Industry Relief & Assistance for the Single Homeless ***(CRASH)****, dedicated to reducing the number of people sleeping on the London Streets through the conversion of empty buildings into temporary shelters.*

NEW COMMISSIONS

ICE RINK, VIENNA

OAP have been appointed to advise on a new ice rink in Vienna which will be used for national and international championship events. Architect: Sepp Muller and Alfred Berger.

LEWIS'S DEPARTMENT STORE, BLACKPOOL

OAP Manchester have been commissioned as structural engineers for the refurbishment of this department store for Chartwell Land, part of the Kingfisher Group. This involves partial demolition of the five storey building with ground floor tenants in continued occupation. Architect: Leach Rhodes Walker.

JUSSIEU LIBRARY, PARIS

Arups with Rem Koolhaas have won the design competition for this £30M project, on the site adjacent to the Arab Institute in Paris.

METHANE: RISK ASSESSMENT

OAP in association with DVn Technica have been appointed by the Construction Industry Research and Information Association (CIRIA) to establish and provide guidance for appropriate strategies for assessing the risk of methane and associated gases to construction.

FIRE STUDY

Arup R&D Fire Engineering team are involved in a pilot study of the health and safety risks associated with fires in occupied buildings for the Building Research Establishment.

APPRAISAL OF SIX CITIES/REGIONS IN RUSSIA

OAP have been commissioned by an international manufacturing company to undertake a desk study of socio-economic and environmental conditions in six Russian cities/regions. The aim is to assist the client in siting new factories as part of a business plan development for joint ventures with Russian manufacturers.

EARTH CENTRE PROJECT, SOUTH YORKSHIRE

OAP Leeds office have been commissioned to carry out an engineering study of a colliery site in Cadeby for development as a tourist attraction and visitor centre to present best innovations and alternatives for a sustainable future for the area. Architect: Feilden Clegg Design.

CKT STUDY, TOKYO

OAP are undertaking a structural engineering concept design study of a 30 storey reinforced concrete residential building in Tokyo for Midi Architects.

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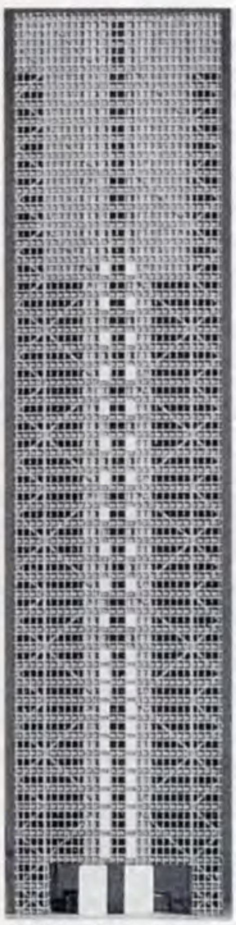
ARUP Focus

Winter 1992/93

ARUPS IN THE USA

In March 1985, Ove Arup & Partners opened an office in San Francisco, expanding to Los Angeles in the following year and to New York City in 1988; they have since grown to be 130 strong. They are not a firm which opens offices 'on spec': the move to the United States came from a project commission - in this case, their appointment by the San Francisco architect Anshen & Allen to be structural, mechanical, electrical and plumbing engineers for the 120-bed Clovis Community Hospital in California's Central Valley. That project was followed by other medical facilities, including the Lucile Packard Children's Hospital at Stanford University, the City of Hope National Medical Center in Southern California, and several projects for Kaiser Permanente, one of America's largest health care providers. In all, Arups have carried out commissions for over $750M of health care facilities in the USA and now are recognised as one of the leading consulting engineers in this field.



747 Flower Street, LA
Wolf+ Architects

Laboratories and Education

Their expertise and experience in health care lead to commissions for research laboratories and similar projects. Ove Arup & Partners have been involved in more than 30 buildings of this kind for industrial and pharmaceutical companies, universities, research institutes and the Federal Government. They are engineers for the extension to the Salk Institute for Biological Studies in La Jolla, California, for laboratories for Amgen Inc, as well as laboratories at Stanford University, the University of Southern California and several campuses of the University of California.

Kaiser Fresno Medical Center (Ratcliff Architects)

Indeed, university work generally has been an important element in Arups' work in America. One of their earliest jobs was a child care center at the University of California at Los Angeles, followed by more work at that campus and others in the University of California system including seismic upgrading of the Powell Library at UCLA, a $70M nursing tower at UC Davis, a 19 500m^2 sports centre at UC San Diego, and buildings at Berkeley, Riverside and Irvine. Altogether, some 60 projects on 22 university campuses across the USA.

Civic and Corporate

Arups are engineers for several civic and cultural buildings: the new Chicago Museum of Contemporary Art, a lightweight roof canopy at the Santa Fe Opera House, the National Inventors Hall of Fame in Akron, Ohio, a library in Phoenix, Arizona, and performing arts centers in Newark, NJ, and Cerritos and Escondido in Southern California.

Corporate and commercial projects are an important part of Ove Arups' practice in the USA. Their work includes offices in Los Angeles, the SwissAir HQ in New York, buildings at the American Airlines Terminal at JFK, and projects such as film archives for Warner Bros, Paramount Pictures and MOMA in New York.

New Directions

Arups' approach to building engineering design - multidisciplinary, integrated, involved - has been well received in the United States. The growth of the practice is one indication of their success. Others are the publicity they have received, which includes features in *Architecture* and *Architectural Record* and the awards made to their projects - most recently an AIA Award to the 747 South Flower Street Tower in Los Angeles - and to the firm itself when, at their 1992 convention, the American Institute of Architects honoured Arups as a 'distinguished engineering firm known for its innovative and influential solutions'.

Since Ove Arup first set up in San Francisco, American architects have increasingly seized opportunities in other countries. One result of this is that Arups in New York and California are now working with American architectural practices on projects in Europe, the Middle East and Asia, frequently working jointly with their local office. This kind of active international collaboration in seeking and executing projects throughout the world marks a further direction for Arups in the USA.