A workman tests the seals on the roof glazing. The prismatic bow-string truss construction is visible.

Arch arrival

Passengers arriving at the UK's first truly international railway station will alight at Waterloo on platforms basking in sunlight under a roof of stunning complexity. James Macneil ***describes how designers and contractors have overcome a constricted site to build the twisting arch roof and the new airport-style terminal.***

DESIGNED to provide a lasting impression for passengers arriving from, or leaving for, the Continent, Waterloo International Terminal is certain to produce high opinions of British roof construction.

Although no more than half-built, the three-pin arch roof spanning the platforms already dominates the site. Formed from blue, banana-shaped, bow-string trusses springing from stub columns on the platform slab's edge and pinned together at the centre, the colonnade catches the eye from any angle. At the northern end, where the stainless steel and glass cladding has advanced several bays down the platform, the train shed roof resembles a 21st century greenhouse.

The 400 m-long roof is the crowning glory of the £130m project to build the first London terminal for trains arriving from Europe via the Channel Tunnel. Construction manager Bovis Construction and client European Passenger Services – a subsidiary of British Rail – are working closely with the designers and trade contractors to conquer the vagaries of the site geometry within a tight 27-month programme.

Project architect Nicholas Grimshaw and Partners, working closely with structural engineer YRM Anthony Hunt Associates, designed the roof

Work continues apace on the new Waterloo platforms beneath the stainless steel and glass arches.

Architect David Kirkland, responsible for the roof, says it "looks very strange and very complex".

But he explains: "Ninety per cent of the design is down to site constraints and physical problems. Instead of fighting them, we've let all the problems come together and dictate how the structure evolves."

Snug fit

Squeezed between the existing rail tracks and the site boundary, the terminal tapers and curves towards its southern end. "It fits the site like a sock," says Kirkland. This funnel-shaped plan translates through the structure to the roof. The most northerly of the 36 arches, closest to Waterloo's concourse, spans 48.5 m while the southern most arch only clears 32.7 m.

The site constraints severely limited where the trusses could spring from. And, because the station has five platforms – two centrally-located sets of double tracks and a single track on the western edge of the building – a symmetrical arch spanning the full distance would not give enough clearance for trains on the western side.

To solve these problems and arrive at a unusual design solution in one swift manoeuvre, the designers decided to shift the central pin between the two trusses as far to the west as possible. "This allowed us to get a tight radius truss on the western side that avoided the train envelope," explains Kirkland. It also helped restrict the building height – an important precondition as originally there were plans to build an office development over part of the terminal.

By the time the roof form was finalised, many of the structural problems were already resolved. YRM Anthony Hunt Associates director Alan Jones says: "The shape isn't something you can arrive at without any recourse to the structure. It is a very pure form that mirrors forces within it."

Each arch consists of two prismatic bow-string trusses connected at a central knuckle joint. The larger truss, which springs from the eastern side of the station, has two telescoping, hollow compression booms on its upper face and a single smaller solid tension bar beneath, to stop the truss spreading under load.

As the arch profile is asymmetric, the small truss is reversed, with two tension rods forming the outer chord and a single, internal compression strut.

Says Jones: "Because we had to set the roof up to suit the substructure, the geometry was just a nightmare. We had to build a full three-dimensional computer model of the whole 400 m length, primarily to check the geometry because the setting out points were just a series of co-ordinates."

Standardisation

Ease of manufacture and erection was not forgotten as the design evolved. "We tried to build in as much standardisation as possible," says Jones. "The central pin joint can take any orientation we want, and where the spans vary, we took the truss cross-section and scaled it down. These measures minimise the number of different truss designs required."

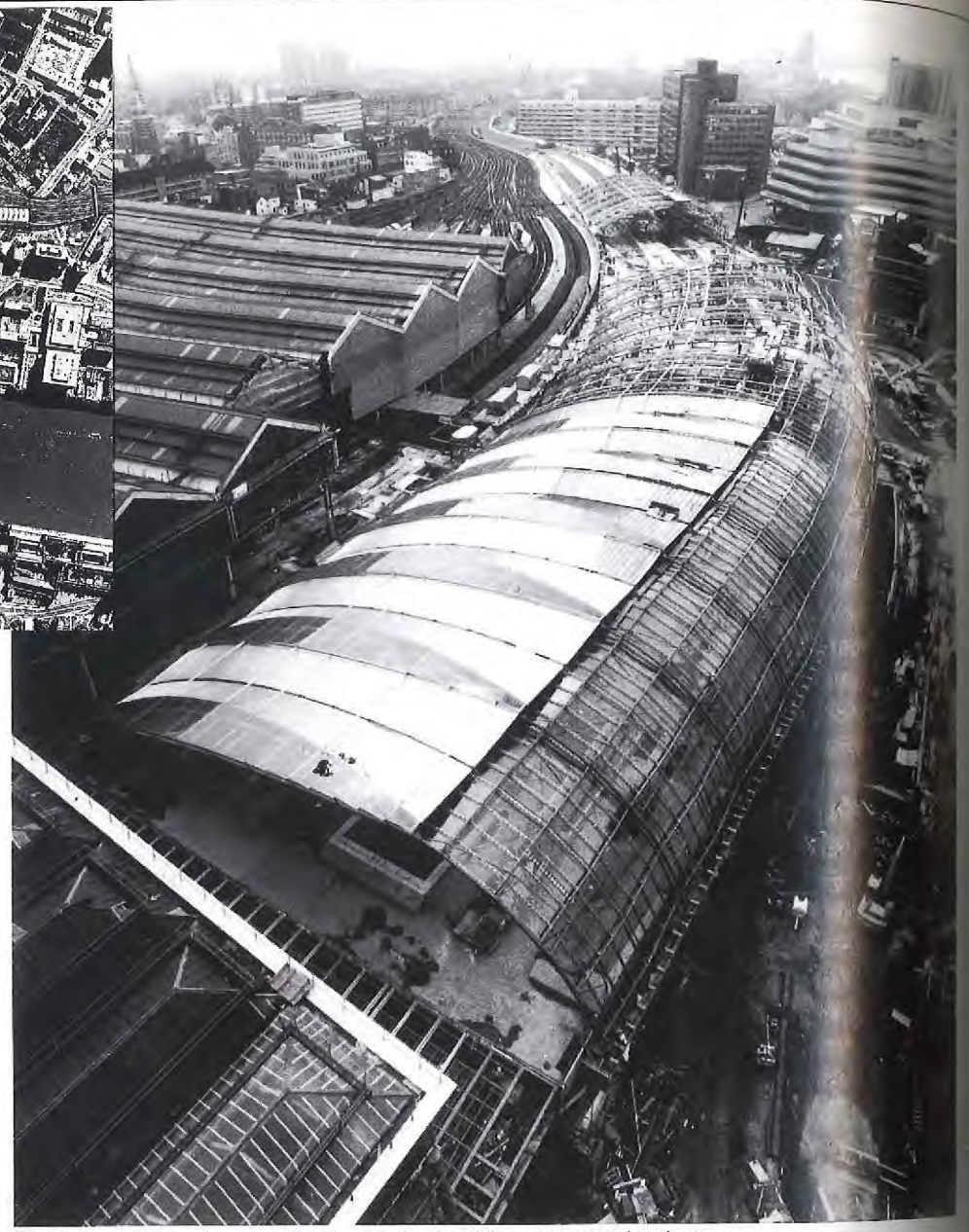
Steel fabrication and erection contractor Westbury Tubular Structures is working on two fronts. Like courting stick insects, pairs of mobile cranes perform delicate tandem lifts to tie each arch together, after painstakingly assembling the truss sections on the concrete deck. "Each crew begins a new bay every two to three weeks," says Patrick Crotty, Bovis's project director.

Briggs Amasco Curtainwall is chasing the steel erectors down the platform, fixing the cladding – a shimmering combination of corrugated stainless steel and toughened glass.

The roof is designed to daylight the platforms and give a view for passengers inside and public outside. The tops of the main trusses are glass-clad, with stainless steel spanning between, while the western side is entirely glazed on the inside chord of the smaller trusses, leaving the steelwork exposed. "It is like the main truss being the lid of a toy box, with the smaller truss propping it open and displaying the trains inside," enthuses Kirkland.

On the western elevation the glazing spans between the trusses. "The spans counter-curve, twist, expand and contract in the space of ▶

How it will look: the banana shaped roof is prominent in this retouched aerial photograph.



The dogleg arched roof cross-section is evident as the 400 m structure takes shape.

► a bay," says Kirkland. The solution was to mimic nature: "The cladding system is like a snake's scales; as the building twists and turns, the horizontal joints just overlap."

The gap between each layer of glass is sealed with a neoprene gasket resembling the wiper blade of a car. Another gasket, flexible in three dimensions, was developed for the vertical joints.

Glass beams

On top of the large trusses, where the glass spans up to 4.2 m, a vertical glazing system is adapted for the task. "We didn't want to confuse the structure by adding more steel members to support the cladding so we used horizontal glass fins as beams to get the glass sheets to span," explains Kirkland.

The edge of the glazing steps along the plan profile of the truss, overlapping the stainless steel like the armour of an armadillo. "Instead of cutting each glass sheet to an angle to fit the trusses' plan profile, we decided to use standard sized sheets of glass," explains Kirkland. "This reduces the cost of the glass by around 30%."

The fixings for the glass panels are formed from three standard cast stainless steel components, bolted together in varying combinations to give all the connections required to fix the roof. "Standardisation allowed us to use casting techniques to produce the fittings in a very economical way," says Jones. There are 299 000 components in the 10 000 m^2 of structural glazing, which weighs 249 tonnes. The terminal also has 10 000 m^2 of stainless steel cladding.

"There was as much time spent on the cladding as on the steel structure," says YRM's Jones. Briggs Amasco director Angus Glennan agrees: "No way does this fit into the crinkly tin image. To devise a cutting schedule for the stainless steel sheet alone has taken a six-month CAD operation."

To simplify their task, the design team used both physical and computer models throughout the development of the structure. It started with a brass model and progressed through an Intergraph computer model, created by YRM, to a 1:10 scale model of a single bay.

The final model was a full-scale erection of two bays of the actual roof at Westbury's site in Yorkshire last summer. "At that stage we were sure of the design but weren't sure how easy it would be to erect," says Kirkland. "In terms of saving time on site the mock-up was absolutely indispensable."

But, spectacular as it is, the roof is a relatively minor part of the terminal work, accounting for 10% of the project value. "It is only the froth on the top of the building," says Grimshaw's team leader, Neven Sidor.

Beneath the glittering crown, a three-level 200 m-long terminal extends from the Network SouthEast concourse at the northern end of the site. The remaining 200 m of the platform sits on a viaduct.

The terminal is designed to operate in a similar manner to an airport. Passengers will wait in departure lounges before boarding the trains, and leave and arrive through immigration and customs control points.

Immediately below the platform is the departures area and, below this, at ground level, is the arrivals hall. The single basement will be devoted to public carparking.

Fast track

Only 15 months after Bovis took full possession of the site, fit-out trades are beginning to move into the cavernous concrete shell. Mike Foulkes, EPS's project director, says: "It is quite an achievement to complete the concrete substructure in this time.

Temporary steel falsework locates and supports the arch sections after they have been craned into place.

'we have given pretty strong advice to the public as to what we are doing and how it will affect them'

Patrick Crotty, project director, Bovis

'it is a fast project, a lot of the design is done on the go'

Mike Foulkes, Project director, BR European Passenger Services

We've got another year to fit it out."

As with those on the platforms above, the trades inside the terminal are working away from the existing station. Glaziers erecting the expanses of structural glazing and blocklayers beginning the internal partitioning are the only evidence of the impending flood of service and finishes contractors into the reinforced concrete shell. "It will then be a matter of sequencing the trades and geometric co-ordination between various services and fittings," says Crotty.

If the three-storey terminal building is overshadowed by the roof, it is unlikely many people are aware of what Crotty describes as the "heart and lungs of the terminal". The labyrinth of brick vaults ►

All change for BR fast-track procurement policy

WATERLOO International marks a departure from British Rail's traditional procurement methods. As a wholly-owned subsidiary of BR, a renowned traditional construction client, European Passenger Services may have surprised observers when it selected construction management.

Mike Foulkes, EPS's project director says although this is not the first time a BR project has used construction management, "before it has always been in partnership with a developer".

Foulkes says the project is an ideal application for construction management. "It is a fast project, a lot of the design is done on the go. It would be difficult to find a main contractor with all the skills required for this site and the project needed an active client."

To ensure the construction management worked, Bovis and EPS have assembled all consultants and major trade contractors on site. "The closer we get the client, designers and construction manager, the better the project runs," says Bovis project director Patrick Crotty. To this end, the client, construction manager, consultants and major trade contractors share a three-storey office perched on stilts over the taxi access ramp on the eastern side of the station.

Bovis also set out to perfect the way it selected trade contractors. "The classic problem of competitive tendering is that you end up with a lowest bidder who you are not sure can cope with the job and a higher bidder who you are confident of," explains Crotty. "The way to avoid that is by prequalification."

Before a contractor is asked to bid, its operational abilities are thoroughly assessed. "If you do this you do away with the questions that come up afterwards," says Crotty.

▶ beneath the existing station is being cleaned, waterproofed and fitted out to provide 9500 m^2 of support facilities and plant rooms. Already major plant items are in place and blocklayers, waterproofers and services engineers are working to convert the area into usable space.

Public information

Under the full gaze of the public are the external infrastructure works. Including a footbridge, pedestrian subways and connection of essential services, these are carefully planned to minimise disturbance to the 250 000 passengers that pass through the adjacent Network SouthEast terminal daily. "We have given pretty strong advice to the public as to what we are doing and how it will affect them," says Crotty.

"But it's not purely altruistic," he confesses. "It is hard enough to build a project of this size on a normal city site. With a site like this anything that reduces problems with the public is worth it." Bovis has anticipated the logistical problems involved and planned the work since early in the project. Says Crotty: "It is getting more complex but it is not new to us. We have been tweaking and updating our outline plans for some time."

"We are buying in a better way," says Foulkes. "It may seem bureaucratic but when you have 80 packages you have to have a firm approach."

Standardised steel components reduce the cost of fixing the glass panels.

Brick vaults beneath the existing station.

Waterloo International Terminal

client
European Passenger Services
construction manager
Bovis Construction
architect
Nicholas Grimshaw and Partners
civil and transportation engineer
Sir Alexander Gibbs & Partners
railway engineer
Cass Hayward & Partners
roof structure engineer
YRM Anthony Hunt Associates
mechanical and electrical engineer
J Roger Preston & Partners
quantity surveyor
Davis Langdon & Everest
type of contract
construction management
duration of contract
December 1990-May 1993
contract value
£130m
principal trade contractors
R O'Rourke & Son (substructure, concrete and demolition, track bed and platform finishes, roads, subways, hard landscaping); Westbury Tubular Structures (train shed roof steelwork); Birse Construction (track support structure); Briggs Amasco Curtainwall (train shed roof cladding and glass walls); How Fire (fire protection); Norstead Engineering Services (mechanical services); J Gardner & Co (ductwork); T Clarke (electrical services); Ellis McDougal (lifts); O&K Escalators (escalators and passenger conveyors); J Murphy (arch facilities – structures).

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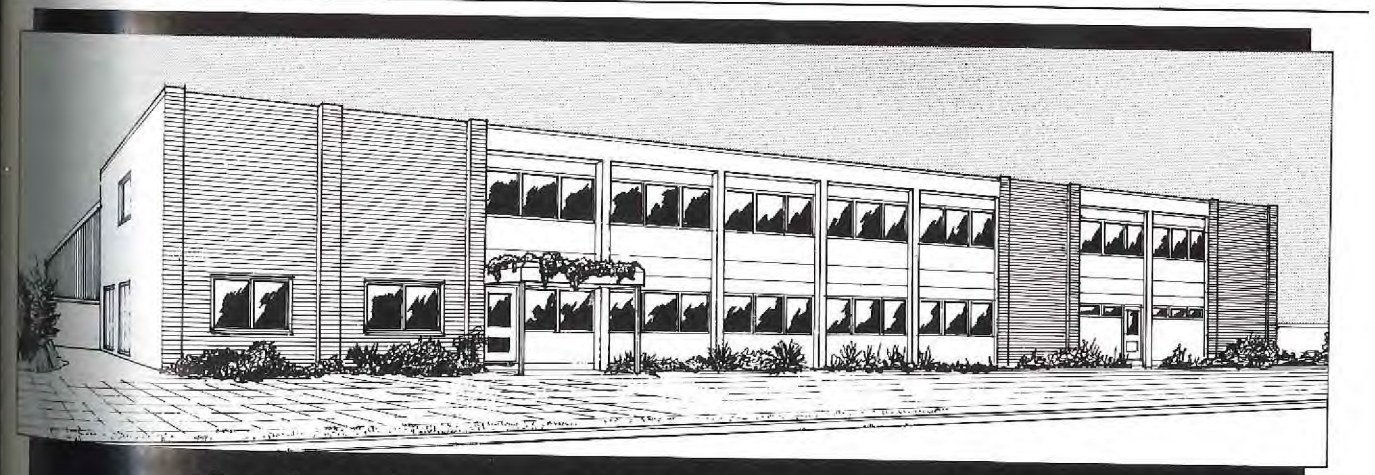

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