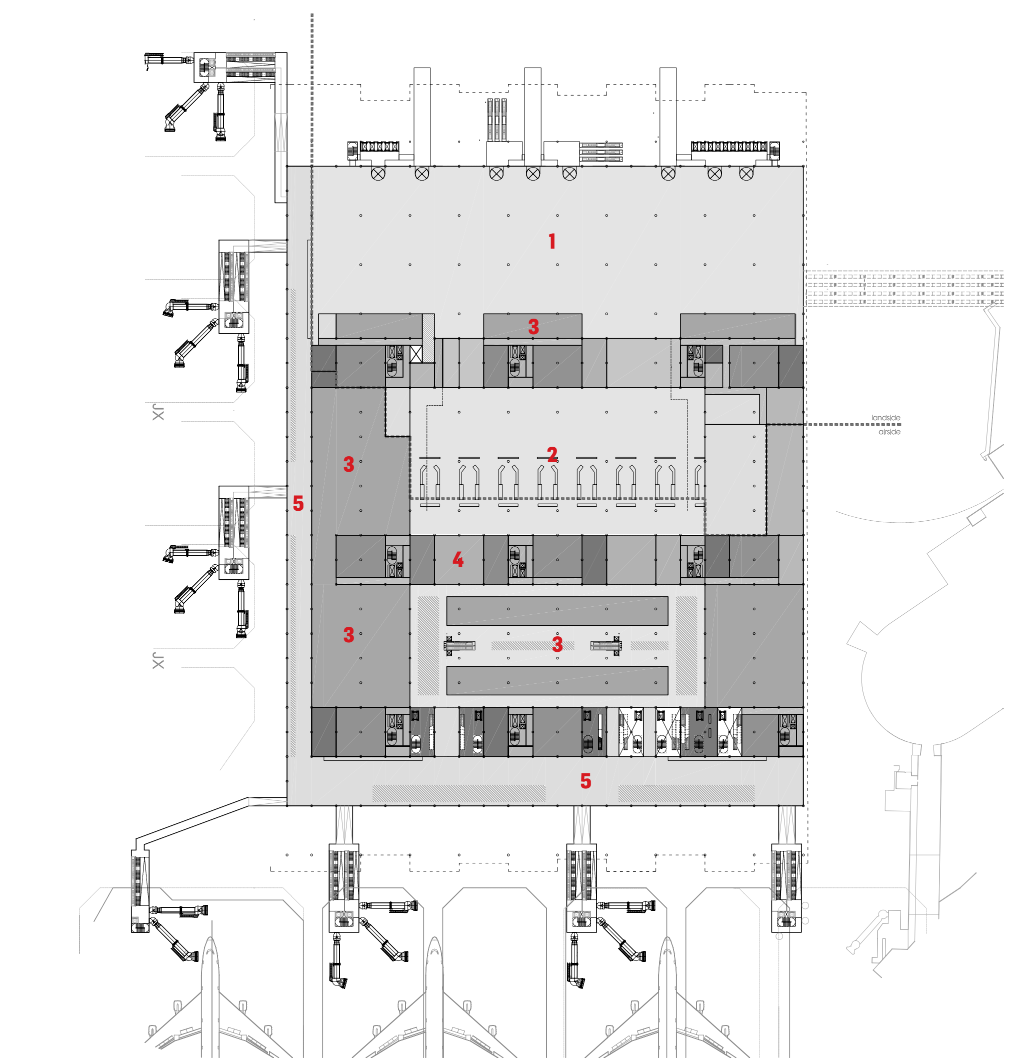
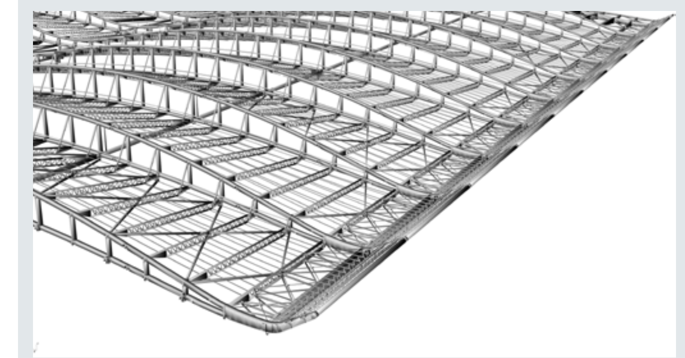


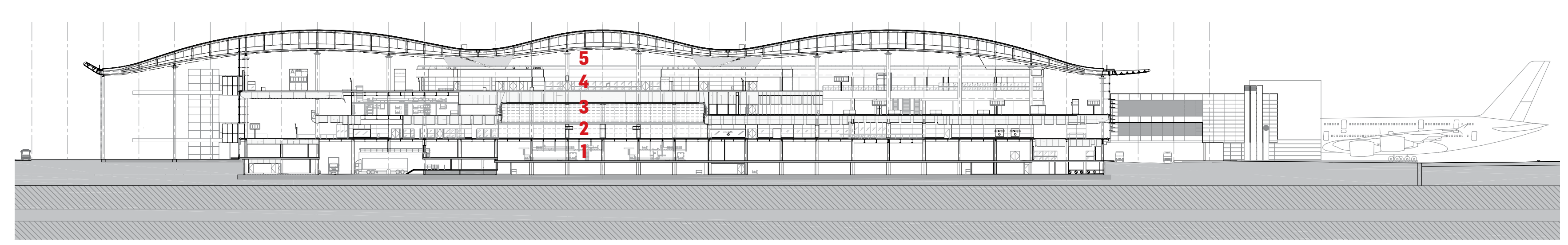
▲ PLAN: DEPARTURES LEVEL

1 Check-in
2 Security
3 Retail
4 Passport control
5 Departure gates



▼ SECTION: EAST-WEST

1 Apron level
2 Arrivals level
3 Gates level
4 Departures level
5 Mezzanine level



ROOF

Terminal 2 is all about the roof. Its undulating wave form is delivered using 18m-long Vierendeel trusses spaced 18m apart and spliced together to form three curved bays that snake across the terminal east to west. The depth increases up to 4.5m and tapers back again to form the north rooflights, which use 6,250sq m of glazing.

Each truss is linked to the next by 1m-deep secondary trusses with diagonal bracing. Struts and plan bracing between secondary trusses provide lateral and torsional restraint for the silicon-coated, glass-fibre fabric soffit, which plays an important acoustic and light-reflecting role in the building.

Because of the access constraints, the trusses were welded at steelwork contractor Severfield-Watson Structures' Bolton factory and transported in 18m sections through the access tunnel out of hours, before being bolted together on site.

The contractor's biggest challenges, according to associate director Tony Whitten, were coordinating with the construction team in order to get the steelwork to where it was needed on such a busy site, and dealing with logistical issues such as ensuring that the cranes didn't interfere with the radar system.

"The roof's design is to optimise the use of natural light," says HETCo design director Teodoro Alvarez, "and while other terminals may have natural light, you can't actually see the sky like you can at Terminal 2. This improves the passenger journey."

The roof steelwork totalled about 5,000 tonnes and was topped with a 50,000sq m Kalzip standing seam roof.

Above us the waves

Luis Vidal's £2.5bn Heathrow Terminal 2 is set to transform the passenger experience — thanks in part to its majestic undulating roof

Text by Pamela Buxton

Three short minutes are all it could take, in a best-case, luggage-free scenario, to get from plane to car on arrival at the new Terminal 2 at Heathrow airport, such is the compactness of the building and the direct and logical navigation.

That is the hope of architect Luis Vidal, who expects the terminal to set new standards for passenger experience with the help of a spectacular, undulating steel-framed roof, designed both to allow in natural light and to aid intuitive way-finding by means of its distinctive contours.

There's not that long to wait to see if the terminal's Madrid-based architect is proved right. The building, which is being built by the HETCo joint venture of Ferrovial Agroman and Laing O'Rourke, is close to completion and on course to open next June.

This massive project, Vidal's first in the UK, is remarkable for the constraints of the site, which hampered development in all directions. As well as height restrictions to maintain the sightline to the control tower, there was the presence of the Piccadilly Line just 7m down, plus the proximity of the neighbouring Terminal 1. Lifting during construction was limited to a height of 44m. To make matters even more testing, all materials had to be brought to site via a narrow access tunnel.

HETCo's response, with the help of structural and civil engineering design detailing from Merebrook Consulting, was to use unprecedented amounts of off-site prefabrication, despite the access limitations. This included hundreds of M&E components and key structures such as the service cores. When necessary, the approach involved transporting components across the runways — flight schedules permitting.

'The design will make you feel relaxed and calm before flying — to me that's important in an airport terminal'

The five-floor terminal is essentially a 220m x 200m building and is generally set out on a modular 9m x 9m grid, rising to 18m x 18m in places to create column-free spaces. The design uses 356mm universal columns throughout the building, apart from 610 circular hollow-section perimeter columns.

Central to the design concept is the prioritisation of passenger comfort through a more direct and logical arrangement that allows them to see the departure gates — and the nearby retail — straight after clearing security. This helps to reduce stress.

"Legibility and orientation are very important to us so that passengers can quickly understand where the boarding gate is ... I can't see the point of keeping passengers enclosed in a shopping mall," says Vidal, who studied at the University of Greenwich before establishing his practice in Madrid.

For most passengers, the experience will begin on entering via bridges from the car park on the western side. Here the entrance forecourt canopy, which shades the facade, rises up with a flick at the extremity to avoid the adjacent car park. Straight ahead is Richard Wilson's 70m-long Slipstream sculpture, based on the aerobatics of a stunt plane and suspended from the entrance forecourt columns. The artwork was a late addition to the design, but due to architectural requirements to maintain a uniform column size throughout the terminal, there was spare capacity in the perimeter columns for the extra loadings.

After the link bridges from the car park, which are designed to compress pedestrian flow, passengers will experience the contrast of the grandiose, light-filled terminal, with a clear route straight ahead to departures. "It's very bright, very inspiring and very transparent," says Vidal.

Visiting before completion, the route is already direct and legible, aided by the three large vaults of the roof that deliberately emphasise the three stages of the process: check-in, security — where floors had to take the heaviest loads — and boarding.

The bulk of the 20,000sq m retail is located in the lofty departure lounge, close to the departure gates on the east and south facades. This is one of the most spectacular spaces in the terminal, with columns rising three storeys to the roof and glass scenic lifts conveying passengers between the two levels of shops and restaurants. There are no separate enclosed gate rooms. Instead, 10m-high windows give views of the airfield to all in the lounge. Even after passing through the gates on the way to the plane, passengers move through corridors with natural light.

The introduction of daylight through north-facing skylights helps orientation and ambience, with the white textile soffit giving a cloud-like effect. "The architectural design will make you feel relaxed and calm before flying — to me that's important in an airport terminal," says HETCo design director Teodoro Alvarez.

The rooflight design also avoids solar radiation and reduces the need for artificial lighting during the day. This contributes to an overall reduction in carbon emissions of 40% compared with the previous terminal through the application of a combination of active and passive energy systems.

The terminal is constructed on a 60,000cu m in-situ concrete raft foundation and, unusually for a building of this size, there are no movement joints. This offers significant advantages in construction methods and lifecycle maintenance, and simplifies services design, as no breaks or flexible joints are required.

HETCo's team was able to eliminate movement joints through the use of heavily braced structural steel cores and heavy feature bracing along the western facade line. The 10 internal and two external cores were built ahead of the main frame to allow the service modules to be fitted in advance. They are a traditional beam and column structure with rigid cross bracing, and reach the full height of the terminal. All thermal, shrinkage and wind load effects are transferred to the cores through the composite floor plates via diaphragm action, and in turn are transferred down the cores, safely to the foundations.

Associated sub-structures have been heavily reinforced to cater not just for today's A380 aircraft but also for larger, next-generation aircraft.

Apart from the roof trusses (see box), steelwork has been designed to act compositely with the floor slabs. There is a mix of traditional in-situ and precast composite slabs. At apron (ground) level, the floor plate has been designed as a reinforced-concrete flat slab tied in to the primary structural columns via steel shearheads. Most steelwork connections are pin, with the exceptions of haunched moment connections to cater for cantilevers.

Although it will be operational from 4 June 2014, the terminal — to be known as Terminal 2: The Queen's Terminal — won't be in its final form for several more years. When the adjacent Terminal 1 is demolished, the phase 2 plan is to expand the building at its northern edge, increasing its size by about one-third. The satellite building Terminal 2B, designed by Grimshaw Architects, is already largely complete and connected to the main terminal by a vertical passenger movement building at the north-east corner.

Terminal 2 will have an initial capacity of 20 million passengers per year, rising to 30-35 million after its expansion. The £2.5 billion project has been one of the largest private sector developments in the UK, with HETCo coordinating up to 3,500 people on site at peak time.

Main image: The three vaults of the roof help to emphasise the three stages of the process — check-in, security and boarding
Right: Columns in the departure lounge rise three storeys to the roof
Below right: Rooflights reduce the need for artificial lighting throughout the terminal

IMAGES: LHR AIRPORTS

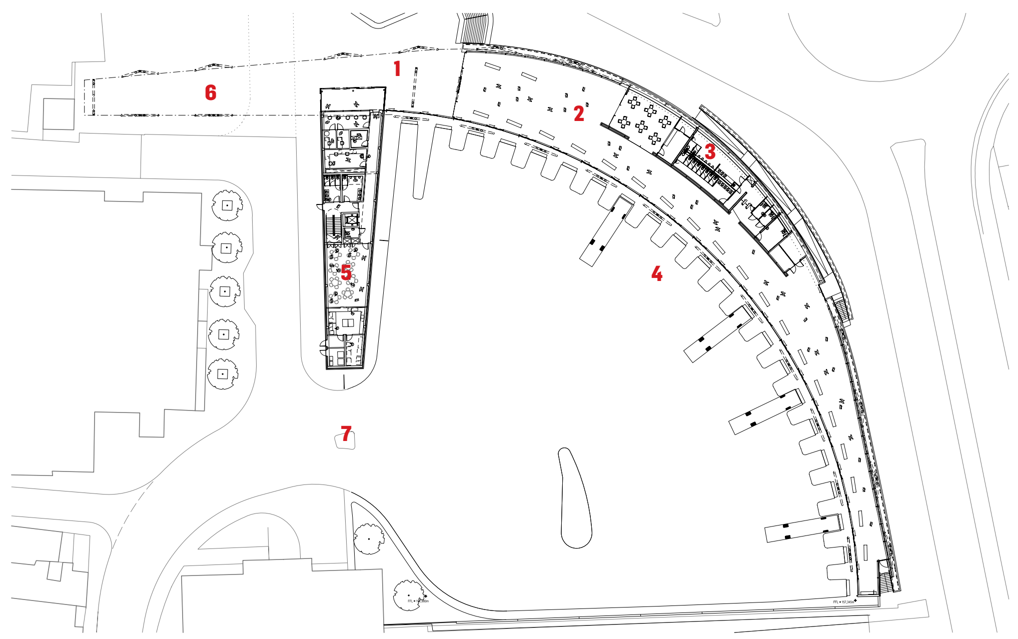
PROJECT TEAM

Client Heathrow Airport
Principal contractor HETCo
Architects Luis Vidal + Architects, with Foster + Partners (project stage E) and Pascall + Watson (fit-out)
Structural designer Ferrovial Agroman Technical Office
Structural and civil engineer (detail design and design support) Merebrook Consulting
Steelwork contractor Severfield-Watson Structures
M&E consultant Hoare Lea
Digital engineer and modular manufacturer Crown House Technologies

First stop on road to renewal

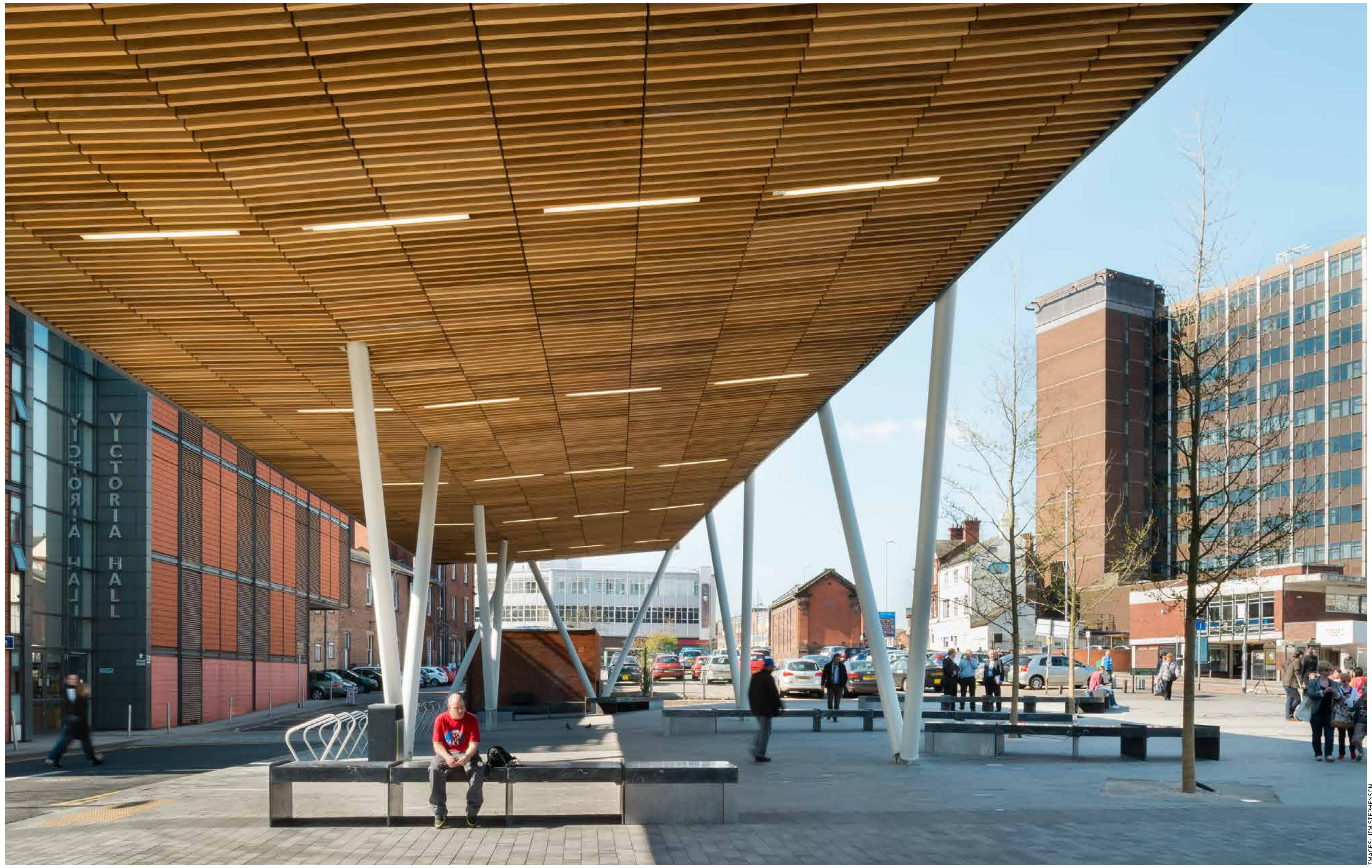
Grimshaw has created a graceful, curving bus station in Stoke-on-Trent that might just become a flagship for the city centre's regeneration

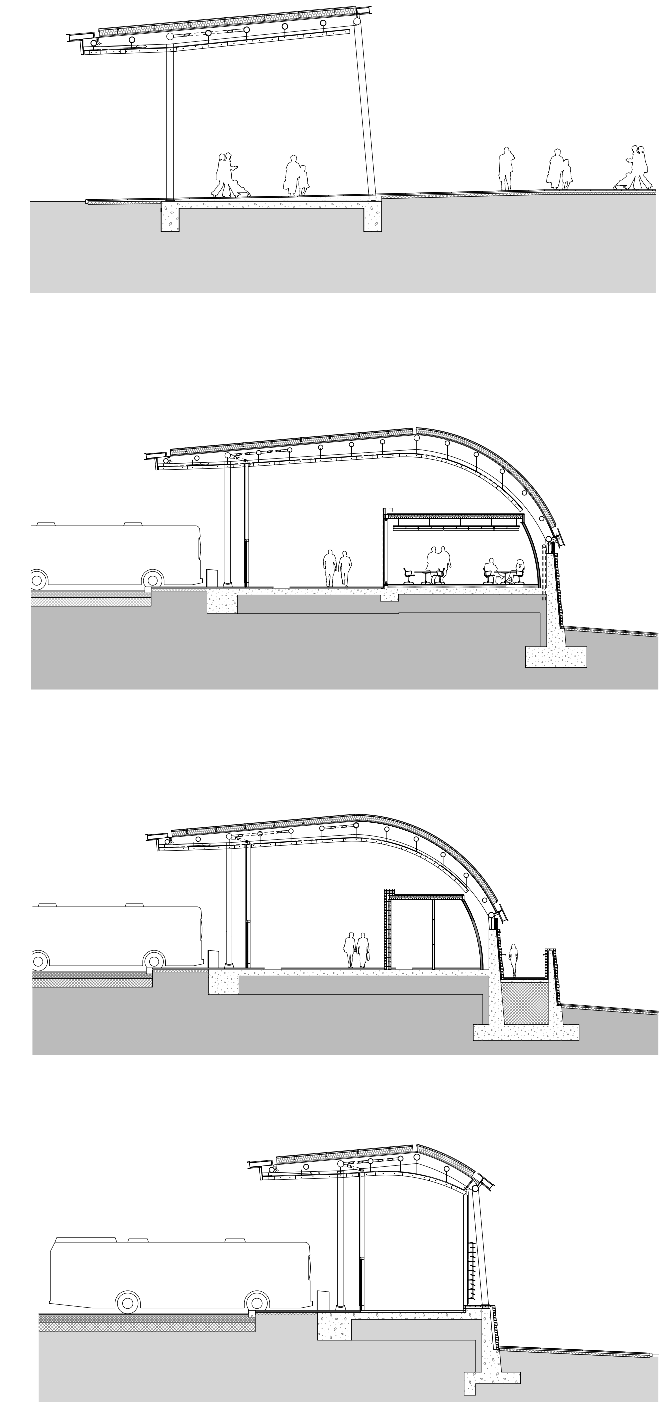
Text by Pamela Buxton



SITE PLAN

1 Main entrance 2 Passenger concourse 3 Passenger facilities 4 Bus stands 5 Driver facilities 6 Extended canopy 7 Bus access





IMAGES: JIM STEPHENSON

Left: The steel-framed canopy extends beyond the original site boundary towards the neighbouring Victoria Hall
Above: Sections at different points in the 170m-long structure
Below: The curving roof line is formed of straight members
Below left: The canopy's timber underside gives a warm character to the interior

Stoke-on-Trent's new toroid-shaped City Centre Bus Station, designed by Grimshaw Architects, is doubly significant for the Potteries city as it seeks to forge a post-industrial identity. Not only is the £15 million building a substantial public infrastructure investment designed by a major architect, but it is key to regeneration plans to transform the adjacent central site into a retail and leisure destination.

Even though it wasn't novated to the build, Grimshaw is highly pleased with how the bus station turned out, in a project completed by contractor Vinci with architect SBS and engineer Alan Johnston Partnership.

Unusually for such cases, the finished station remains largely faithful to the original design concept, despite value engineering. According to Grimshaw associate Richard Blackwell, this was largely thanks to the commitment of the client, which "hung on to as much of our intent as possible".

The result is a distinctive, 170m-long, curving form, topped with a sculptural aluminium roof, located on the edge of the Hanley district on a major route into the city centre. As Grimshaw suggested in its competition submission, the station's steel canopy is extended beyond the original site boundary towards the neighbouring concert venue, Victoria Hall, forming a new public space that engages with the city.

While the architect aimed to create a "sculptural, engaging form" on the city fringe, the

Unusually for such cases, the finished station remains largely faithful to the original design concept

design strategy was also driven by the need for separate pedestrian and bus circulation. In total, the station provides 22 bus stands plus passenger accommodation and shelter from the elements, and a separate pavilion for driver facilities.

With buses entering and exiting via a pre-designated access point at the rear of the site, it made sense to maximise the available space by pushing pedestrian accommodation back to the perimeter, curving it around a corner next to a roundabout and facing inwards towards the city centre. This forms a clear edge to the site, and is described by the architects as a "contemporary shield". As most passengers will be exiting towards Victoria Hall, the station widens from 5m to 14m (it is 10m at the main entrance) to accommodate the accumulation of people as they alight at the bus stands and progress through the building towards the city centre.

Grimshaw's design concept, engineered by Arup, takes inspiration from the coal seams that run beneath the site in the creation of a raised plinth clad in a blue-grey Staffordshire brick.

Above this sits the glazed toroid form, topped with the crisp, aluminium-clad standing seam roof. Passengers gather at each gate, with the arrival of the bus triggering the recessed glass doors to allow them to embark. In this way, the bus apron is protected from straying passengers the rest of the time.

The form is animated by a

meandering eaves line, supported on V-shaped columns, which gets closer to the ridgeline of the roof as it moves towards the entrance. As it extends beyond this into the new public space by Victoria Hall, the roof becomes a structural canopy.

Where the station faces the roundabout, it is protected by a higher brick elevation, but on either side of this, full-height glazing provides both natural light and views out over the surrounding area. The granite-floored passenger concourse is at a gentle fall in response to the 3m drop across the site and the interior is given a warm character by the timber lining on the underside of the canopy.

Passenger facilities are situated towards the middle of the bus station along the rear wall in a small pavilion, while driver facilities are located in a separate concrete-framed building near the station entrance.

Steel was the obvious choice for the main structure, and was provided by steelwork contractor Henry Smith. "Steel offered slenderness and the flexibility as a skeleton that could achieve what we wanted, together with robustness," says Blackwell.

The hope is that the bus station and its neighbouring redevelopment will help to kickstart much-needed regeneration for a city that, despite being formed a century ago by the amalgamation of six towns, is still striving for a unified identity.

"There is the real sense of it being more than a bus station and a regeneration project for a very sceptical audience," says Blackwell.

PROJECT TEAM

Client Stoke-on-Trent City Council, Realis Estates
Main contractor Vinci Construction
Architect (concept) Grimshaw Architects
Architect (delivery) SBS Architects
Structural and civil engineer (concept) Arup
Structural engineer Alan Johnston Partnership
Steelwork contractor Henry Smith
Landscape architect Planit

IMAGE: BLACKWELL/GRIMSHAW

CANOPY

There were changes to structural engineer Arup's original design for the canopy as part of a value-engineering exercise. This meant that the proposed fabricated, tapering, plated sections were replaced by far more economical proprietary sections, rolled to the correct radius, in a stepped arrangement.

This gave"'huge savings", according to Alan Johnston Partnership engineer Danny Sinclair, who adds that the profile is, in any case, covered by western red cedar cladding to the soffit.

Roof purlins, originally circular hollow sections, were also changed to universal beams, which were not only cheaper but were more compatible with the fixings for the Kalzip roof. Although the roof line gives the appearance of curving, it is formed by straight members bolted together.

The canopy was constructed with the help of temporary steelwork, which enabled contractor Henry Smith to construct four frames at a time using the retaining wall for added stability.

Arup project director Sophie Le Bourva says the completed structure is true to the original intent, despite the changes. "It's quite a faithful rendition … They really kept the essence of the ideas."

V-SHAPED COLUMNS

The V-shaped columns are one of the few visible expressions of the steel structure. They support the roof rafters without the need for much additional bracing along the bus-stand side. Each column was formed from two 8m-long, 273mm-diameter galvanised sections, which were brought to site separately and bolted together.

Changes in the site contours mean that the height and the angle of the V alters as the canopy progresses.

In association with The British Constructional Steelwork Association and Tata Steel

Fire protection that's made to measure

The author of a new BCSA guide outlines 10 key considerations when tailoring fire protection to the design of steel-framed buildings

Text by John Dowling Illustration by Nick Lowndes

There are many issues that designers should be aware of when considering the fire protection in new steel-framed buildings. Fortunately for architects, there are usually only two distinct stages: working out the fire period and then deciding what form of fire protection to use (figure 1). Below we discuss the 10 things that architects need to know to ensure the best and most economical solution.

1. It's not all that complicated

Don't be daunted. The only complication arises when deciding whether to use an engineered approach to the fire precautions, one of the prescriptive approaches found in documents such as Approved Document B (in England), or the risk-based approach of BS 9999.

2. Fire tests are far tougher than real fires

Fire protection for structural steel is assessed in a standard fire test, with temperatures rising quickly and increasing indefinitely. Consequently, the standard fire test is much more severe than any fire that is likely to happen in practice, since in a real fire, once the combustible material or fire load has been consumed, the fire will decay and/or move (figure 2). Therefore, one can be confident that buildings that have properly specified and installed fire protection will not fail in a fire.

Fire protection calculations for steel are usually based on limiting temperatures of 550°C, where steelwork is exposed on all four sides, and 620°C, where a fully-loaded beam is supporting a concrete floor slab (figure 3).

It is important to note that fire resistance is not the length of time that a structure will survive in a real fire, but a standard measure for comparing the performance of different designs in a consistent manner.

3. There are different ways to determine fire resistance periods

This is usually done either through the use of sources such as Approved Document B or BS 9999, or with reference to sector-specific fire rules — for example, in schools and shopping centres. Most buildings in England and Wales use Approved Document B (figure 4), in which fire resistance periods vary according to the building occupancy and its height, changing at 5, 18 and 30m. This is measured as the distance from the ground to the upper surface of the top floor.

Since most non-residential, multi-storey buildings in England and Wales are classed as shops, offices and assembly, and the majority are between two and four storeys, the dominant period of fire resistance is 60 minutes.

Using BS 9999, fire periods can be tailored according to risk, governed by occupancy characteristics and fire growth rate. As is clear from figure 5, this can result in reduced periods of fire resistance, provided that certain ventilation conditions are met.

Alternatively, an engineered approach to fire precautions can be used, especially in large and complex buildings requiring high periods of fire resistance, but it needs to demonstrate that reductions can be justified.

Specific rules for certain sectors and types must be observed. For healthcare buildings, for example, best practice guidance and recommendations for fire precautions are set out in Health Technical Memorandum HTM 05-02.

4. BS 9999 can make your build more cost-effective

Fire precautions for buildings outlined in BS 9999 are based on an assessment of how risk is created in fire. This more tailored approach is an alternative to the one-size-fits-all, prescriptive method of Approved Document B, which potentially provides a more conservative, and therefore more costly, solution.

5. Thin-film intumescent coatings are by far the most popular option

These are now overwhelmingly the most common fire protection solution for structural steelwork, with a 70% market share in new buildings compared with 20% in 1992.

These coatings are predominantly used in buildings where the fire resistance requirements are up to 90 minutes, although some products provide up to 120 minutes. They can be water or solvent-based, the former being most frequently used in on-site applications and the latter most commonly used off-site.

Traditionally, thin-film intumescent coatings were used where aesthetics were important. However, they are increasingly used where they are not visible. Care should be taken not to specify decorative or aesthetic finishes where they are not necessary as this will add unnecessary cost.

6. Don't forget other forms of structural fire protection

Other common forms of structural fire protection are board, sprays and flexible blankets. All are in widespread use, although, of these, boards are the most common.

When specifying boards, one should be aware that there are two "families" of products. Heavy boards are usually used where aesthetics are important as they can take renders and decorative finishes. Lightweight boards are usually used where appearance is not such an issue. It is important that specifiers recognise these distinctions as there is a significant difference in cost between the two types.

7. Off-site application isn't always the answer

The development of thin-film intumescent coatings that can be applied off-site has been very successful in the UK. It is a premium process but has the advantages of taking fire protection off the critical path, quicker construction, improved quality control, reduced site disruption, cleaner sites, improved site safety and easier servicing installation.

Specifiers should be aware that off-site-applied thin-film intumescent coatings are used mainly for non-aesthetic end uses. Aesthetic finishes are possible, but they require an additional level of care and attention. This is because some damage in transit is inevitable, even though applicators work to minimise it. It is difficult (but not impossible) to repair damage to match the appearance of the rest of the coating, but this adds a layer of complexity to the work.

8. More steel can reduce overall costs

Generally speaking, the bigger the section, the thinner the fire protection. This is because big, heavy sections heat up more slowly than small, slim sections.

Usually, it is not particularly cost-effective to increase the size of the section to decrease the amount of fire protection. However, when multiple layers of protection are required, it can be more economical to trade more steel for a single layer of protection material. This can be particularly effective when using thin-film intumescent coatings.

9. Secondary beams in composite floors don't always need protecting

A comprehensive series of fire tests carried out by the steel construction sector and BRE has established that a continuous composite steel floor provides enhanced fire resistance not indicated by conventional tests on isolated components.

This has led to the development of design methods that allow composite steel deck construction to be built with unprotected secondary beams. By protecting primary beams and columns but leaving the secondary beams unprotected, the slab is able to develop tensile membrane action, as long as there is adequate vertical support on all four edges of the slab panel and adequate reinforcement.

As figure 6 shows, this action works in two stages. Reinforcement can be calculated using the TSlab tool, downloadable from www.tatasteelconstruction.com.

10. Steel can often be reused after a fire

As a general rule, if steel is straight and there are no obvious distortions after a fire, then it is probably still fit for purpose. If standard grades of structural steel have not been heated beyond 600°C, there will be no metallurgical changes on cooling. If the steel temperature has risen above that, it is likely that it will be distorted and/or buckled.

In the event of a fire, checks should always be carried out. In particular, bolts should be removed and inspected. Hardness tests can be carried out to determine ultimate tensile strength, as this can then be related back to tensile strength. If doubt persists, coupons should be taken from the steel for testing.

Where small deflections or distortions in the steelwork are visible, the structural engineer must calculate the effect under load to make sure that the performance of the structure is not impaired.

John Dowling is the author of Steel Construction: Fire Protection, which is available at www.steelconstruction.info

FIG 1. THE TWO STAGES OF SPECIFYING FIRE PROTECTION

FIG 2. BEHAVIOUR OF FIRE IN TEST vs REAL FIRE

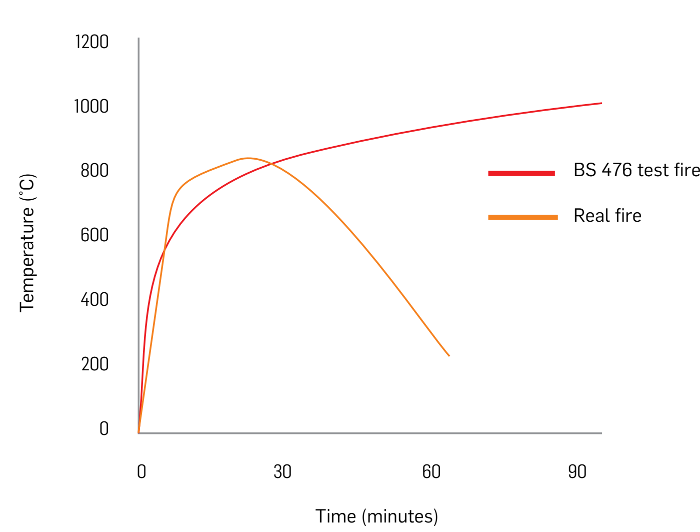
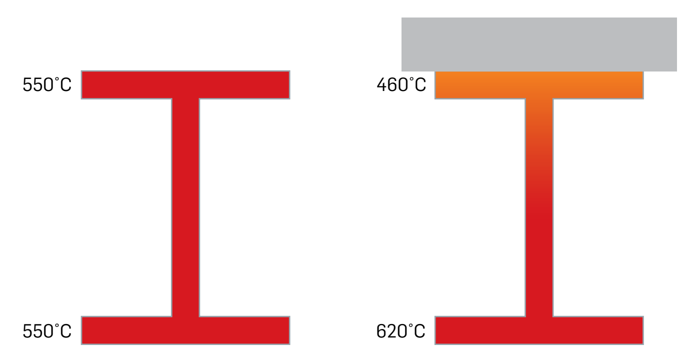


FIG 3. TEMPERATURE LIMITS FOR FULLY AND PARTIALLY EXPOSED STEEL BEAMS



A fully loaded beam, exposed on four sides, fails at 550°C

A fully loaded beam, exposed on three sides, fails at 620°C

FIG 4. FIRE RESISTANCE PERIODS IN APPROVED DOCUMENT B

Purpose of building	Minimum periods of fire resistance (minutes)			
	Height of top floor above ground			
	≤ 5m	≤ 18m	≤ 30m	> 30m
Office	30	60*	90*	120 + sprinklers
Shops and commercial	60*	60	90*	
Assembly and recreation	60*	60	90*	
Industrial	60*	90*	120*	
Storage	60*	90*	120*	
Car parks — other	30	60	90	
Car parks — open	15	15	15	60

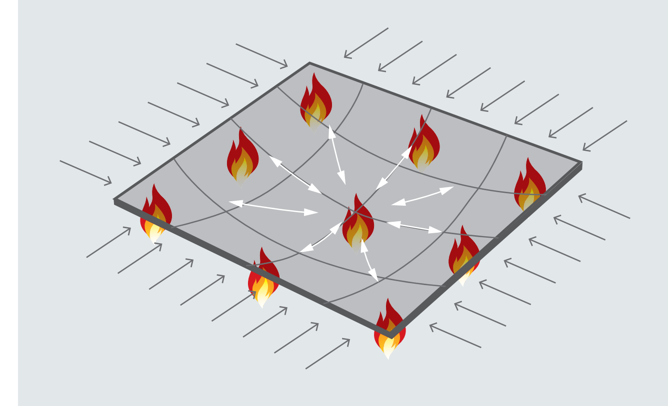
* Reduced by 30 minutes when sprinklers are installed

FIG 5. COMPARISON OF APPROVED DOCUMENT B AND BS 9999

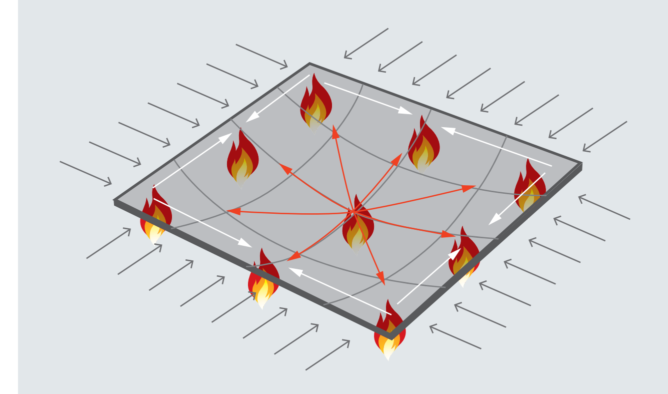
Building description	Minimum periods of fire resistance (minutes)		
	Approved Document B	BS 9999 without sprinklers	BS 9999 with sprinklers*
Two-storey open-plan office of <1,000sq m ground floor area	30	15	15
Open-plan office between 30m and 60m in height	120 + sprinklers	n/a	60
Three-storey department store	60	45	30
Department store between 11m and 18m in height	60	75	60
Two-storey leisure centre	60**	30	30

* Fire growth rate can be reduced by one level if sprinklers are installed (section 6.5)
** Reduced by 30 minutes when sprinklers are installed

FIG 6. ENHANCED FIRE RESISTANCE IN STEEL COMPOSITE FLOORS



The diagrams show a steel composite floor with unprotected secondary beams. At low deflections, there is compressive arching of the slab against the adjacent structure and thermal buckling of the slab



At high deflections, tensile membrane action develops with biaxial tension in the reinforcement at the centre of the slab and a compressive ring around the edge of the panel