

Design and construction of Wembley Stadium Station Footbridge

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Synopsis

The Wembley Stadium Station Footbridge (Fig 1) is a new pedestrian bridge linking Wembley Hill Road / Wembley Triangle and South Way in London, UK and serves as a crucial conduit for pedestrians visiting the new Wembley Stadium. It spans the Chiltern line suburban railway services between Marylebone, Aylesbury and Birmingham (Fig 2).

Halcrow Group Ltd was appointed by London Borough of Brent and the London Development Agency to undertake project management, design development, and site supervision on the strategically important southern stadium approach. The bridge has two primary functions, firstly to carry pedestrians over the railway and provide access via staircases and lifts to the platforms: this access is provided either side of the bridge one side controlled for use on stadium event days and the other side being part of the station revenue protected area. Secondly, the bridge forms a landmark structure which is easily recognisable, opening up the gateway to the national stadium along the Wembley Route, and

serving as an attraction for future development, investment and regeneration.

A number of options for the bridge form were considered. The selected option was judged to have a high visual, aesthetic, landmark and curiosity value and one that would create an identity for the location, fulfilling the requirements to enable regeneration of the area. It was also considered to have the lowest risk when considering programme, construction, cost, security and technical approval.

Stakeholder management

Few infrastructure developments have attracted as much public attention as the new Wembley stadium and a consensus for the bridge designs was required from a wide range of stakeholders ranging from the police to Network Rail, the London Development Agency, the Department for Culture, Media and Sport, the Highways Authority and the London Borough of Brent. The bridge was required not only to service around 30 events that Wembley stadium is scheduled to stage each year and fit in aesthetically with the showpiece stadium, but also to tie in with the broader regeneration of this part of London. The project timescale was extremely tight: 21½ years from commencement of design to completion.

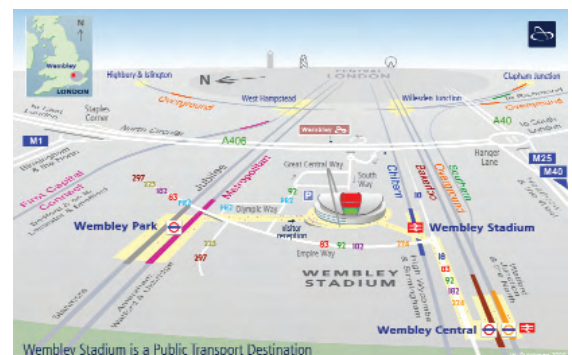
Planning

The Wembley Link development proposals were designed to respond to regeneration objectives set by the London Borough of Brent and the Mayor's London Plan. The need to link the Town Centre to the new National Stadium and the National Stadium Policy Area was recognised in the Brent Replacement Unitary Development Plan. This was followed by 'Destination Wembley' – a framework for development that was adopted by Brent as Supplementary Planning Guidance. Provision of the 'Wembley Link' was designed to encourage the comprehensive development and regeneration of the land between Wembley Stadium and the eastern end of Wembley Town Centre and to bring vacant and

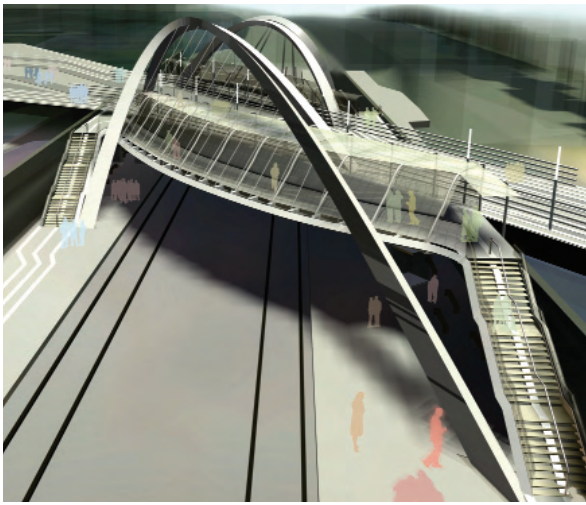


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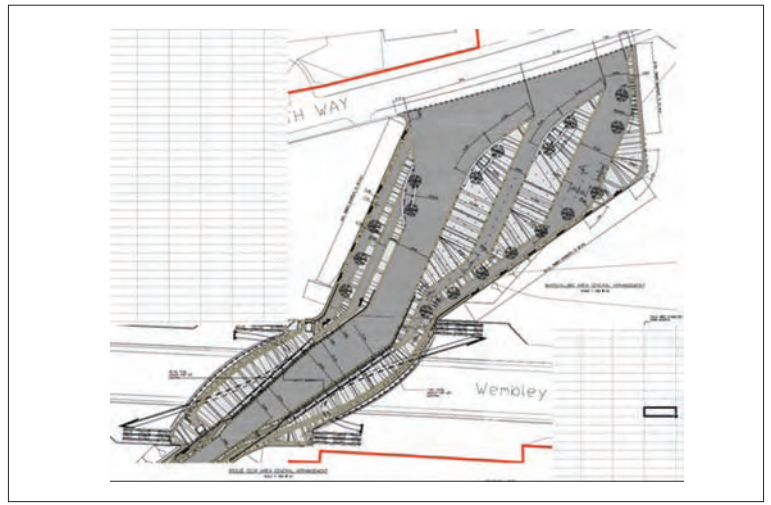
1 Wembley Stadium Station Bridge
2 Location map (Courtesy: Wembley Stadium)



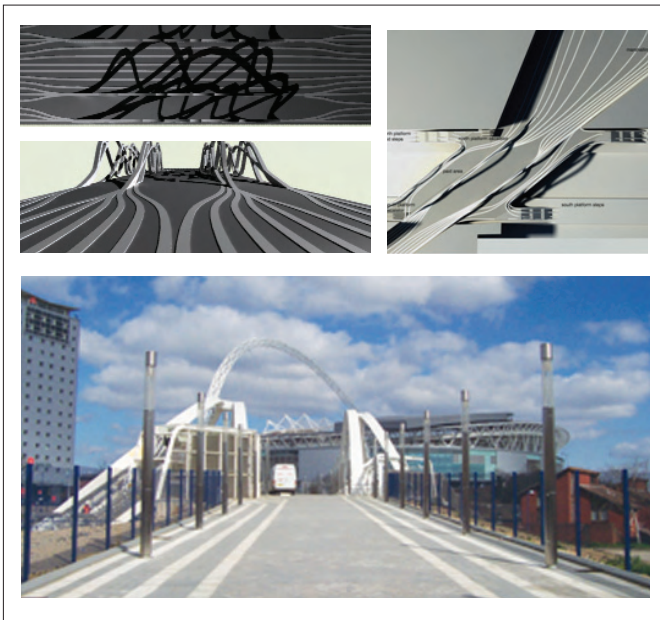
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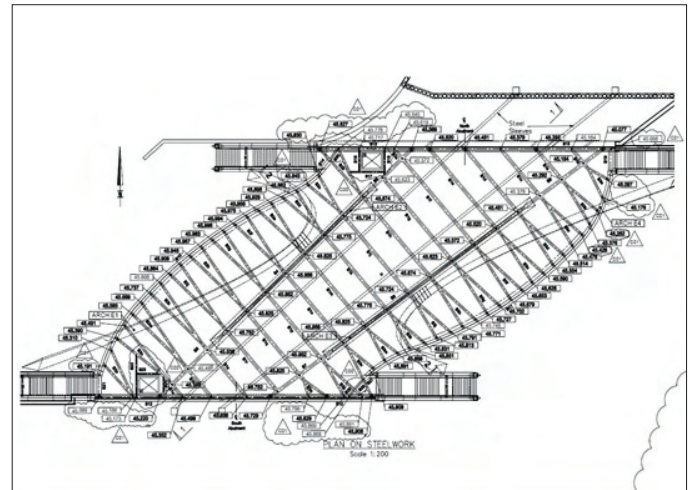
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- 3 Planning rendering (Courtesy: Marks Barfield Architects)
- 4 Deck layout
- 5 Deck spatial delineation concepts
- 6 Plan of deck steelwork

derelict land back into beneficial use. The new bridge (Fig 3) was seen as an essential component in fulfilling this strategy.

Marshalling area – crowd modelling and architectural studies

At its peak, crowd flows of up to 20 000 people per hour exit the stadium progressing toward Wembley Stadium Station. To cope with these exceptional flows the bridge is 30m wide and provides for station users and queuing areas. The marshalling area and Station Square (Fig 4) has an overall area of 4026m² which is large enough to provide for approximately 19 000 people per hour, allowing for a central thoroughfare of 12 000 people per hour to pass through and over the bridge to the more remote Wembley Central Station. This means the estimated remaining 7000 people per hour accessing the Stadium Station northbound and southbound platforms need to be held within the station square and not impede the continuous flow of people through the central quarter of the square.

The 7000 people accessing the station platforms are separated through two areas, northbound and southbound, in which, the total number of passengers is split into two thirds, i.e. 5000 northbound and 2000 southbound per hour or *vice versa* (depending on the event and the teams playing). These flows have been established from the staircase capacity for moving passengers onto and off the platforms within a certain timescale.

In addition to the designated southbound and northbound passengers, there is a further area provided for disabled access

and other customers. The total area available is 293m²; therefore the holding area can cater for a maximum of 651 passengers.

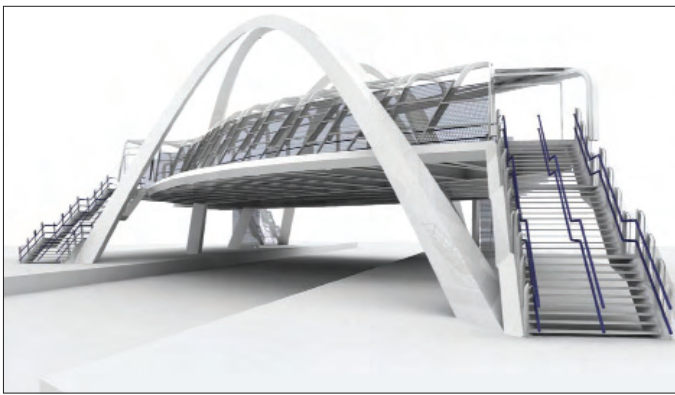
The architect's vision was to provide linear elements to both define the space and change its scale. Using a limited palette of materials, the project successfully deployed large areas of a single material type, breaking it up with thin linear elements which stop the dominant material becoming overbearing. The linear elements assist in providing direction and focus to the space.

The palette of materials for the marshalling area reflected the ambition of the client to create a high quality environment which could define the overall level of finish for the further development of the masterplan. Granite, marble, hardwood and stainless steel were all materials which added value in terms of being attractive, hard wearing and low maintenance.

Wembley themes of railway lines and sports tracks led to the spatial delineation designs that were developed (Fig 5).

Description of the structure

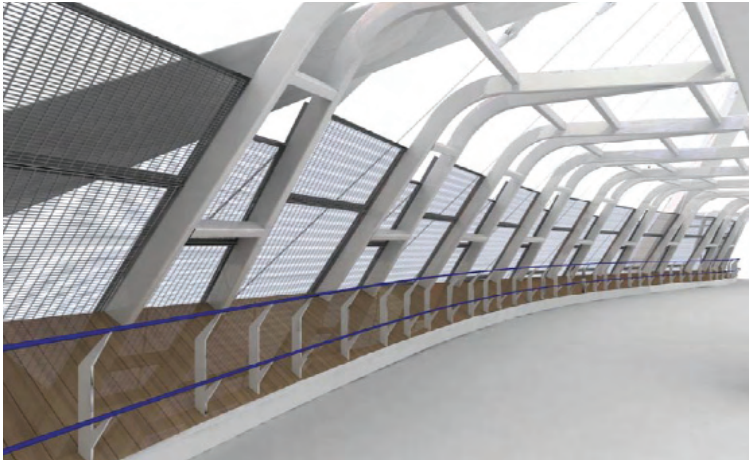
The bridge at Wembley stadium station is a complex 55m curvaceous structure skewed across the tracks and platforms (Fig 6 and 7). The superstructure comprises two pairs of twin asymmetrical parabolic steel arches which divide the deck longitudinally into three walkways. The inner arches pass through the deck over the station platform area and the legs of all four arches are sprung from the back of the widened platforms and opposite the stair cases and abutment walls. The external arches



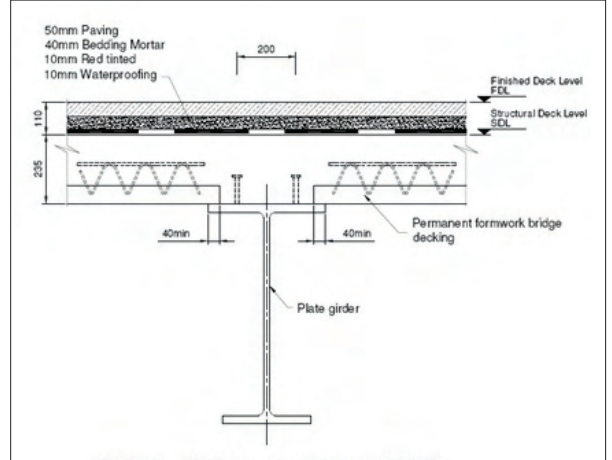
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incline inwards and join the internal arches at their crown (Fig 8).

Each of the steel arches is also joined at the deck level with the longitudinal steel beam which, together with the transverse beams, provides the primary support of the deck slab for both the side and central spans. Hanging steel cables (vertical and inclined) from the internal and external arches support the suspended central bridge spans. The longitudinal and transverse beams are all connected to a transverse steel diaphragm at the abutment. The bridge deck is asymmetrically skew, both edges are curved in plan and the outer walkways are enclosed with mesh (Fig 9).

The cable suspended spans vary in length between 28.6m to 34.7m at deck level whilst the length at both bridge ends making up the side spans beyond their respective arches, varies between 7.2 to 8.9m with the span terminating at the abutment walls. Access to Chiltern Railway platforms is provided by stair accesses at four corners of the bridge and lifts for disabled access are provided at both ends of the western walkway. The stair cases are *in situ* concrete/steel structures and although partially supported by the bridge deck, are not rigidly connected to it and therefore do not provide bridge lateral restraints, but they will accommodate vertical deck deflections. The platform lifts are supported by a steelwork frame attached to the lift pit walls.

The walking areas of the deck are formed by an *in situ* concrete slab spanning between transverse steel beams with glass reinforced plastic planks below as permanent formwork (Fig 10). The end supports are cantilevered, solid concrete wall abutments extended over the full width of the bridge deck so retaining the approach embankment on the south side.

The springing/foot of the steel arches is rigidly fixed to the foundation pilecaps. The bridge is articulated on six free sliding mechanical bearings seated under each diaphragm at the north and south abutment with one fixed and guided mechanical bearings arranged along the longitudinal centreline of the structure.

Materials

Each arch was fabricated from structural steel plate (Grade S355J2G3 to BS EN 10025) to form a continuous and variable size triangular hollow section. Cable assemblies (Fig 11) comprised 35mm and 70mm diameter spiral strand cables, the properties of

7 View of bridge from platform level
(Courtesy: Marks Barfield Architects)

8 View of deck at night

9 View of upper deck (Courtesy: Marks Barfield Architects)

10 Typical steel beam

the spiral strand in accordance with EN 12385-10:2003 *Spiral Ropes for General Structural Applications*. The smaller diameter cables were fitted on the external arches, the larger diameter cables fitted on the internal arches.

The sockets comprised Stylite sockets designed in accordance with ENV 1993-2 *Design of Steel Structures – Bridges – Annex A* and attached to the cable in accordance with EN 13411-4: 2002 *Terminations for Steel Wire Ropes – Safety – Metal and Resin Socketing*.

During manufacture, the cables were fully prestressed by cyclically loading to between 10% and 50% of specified minimum breaking load until a stable apparent modulus of elasticity was achieved.

Foundations

The staircases are *in situ* concrete/steel structures supported at deck level on the deck edge beam and abutment and at platform level on discrete independent foundations. The lift structure is self supporting on independent foundations and accommodates vertical deflections of the deck. Both abutments and steel arches have cast in place bored piled foundations with *in situ* pile caps. The springing/footing of the steel arch is rigidly fixed to the foundation pile cap with cast in holding down bolts. Likewise, the springing/foot of the steel arches is rigidly fixed to the foundation pile caps.

Piling comprised reinforced concrete rotary bored piles of 600mm diameter. Pile lengths varied from 17.0m to 27.0m. Pile boring used standard R312 HD and R618 rigs with attendant handling cranes. The R312 HD rotary mode rig is a modern hydraulic rig, with extendable tracks and mast height of 17.8m allowing increased stability. Plant was slew restricted to prevent slewing within 3m of Network Rail Infrastructure. Although no piling

works required work on the operating rail infrastructure, all piling works were undertaken at night with working planned to coincide with T(III) booked possessions to ensure that piling works and cage installation were carried out when the railway was non-operational. On completion, all piles were integrity tested.

Bridge steelwork – procurement

The feasibility of pre-ordering structural steelwork under a separate contract between the client and a steelwork fabricator, taking into account any restrictions imposed on the procurement process by the EU procurement rules, was examined. Because of programme constraints it was agreed that the structural steelwork be pre-ordered by means of contracts between the client and steelwork fabricators for the supply and delivery to site of fabricated steelwork elements. The value of the steelwork contracts was in the order of £2.5M.

Steelwork – erection

The steelwork erection methodology involved the assembly and welding of four primary arches and the central deck under a weekend possession with remaining steelwork, hangers and erection of staircases under a separate weekend possession.

Each arch was laid out on assembly jigs and stillages in a horizontal plane and joined in a predetermined sequence. The layout allowed cranes to be rigged and for each to be checked within the pre-calculated lifting radius of the crane. Assembly commenced from the crown sections progressing in both directions towards the arch base. On completion of each arch welding, a full dimensional survey was carried out and cross-checked against the actual holding down bolts in the foundations.

Lifting

All arches were lifted into the vertical position using a large

spreader beam (to minimise arch deflection) and a large AK 680 mobile crane plus two smaller cranes which tail lifted the arch bases. Each arch was swung out over railway and then lowered down over the holding down bolts on to pre-levelled steel laminated packs. Temporary shear keys were positioned in the foundations so that as the crane lowered the piece off, the base plate at each arch end could be accurately positioned by jacking and then packing off the temporary shear keys. With the crane released and all temporary works locked and signed off, the holding down bolts were tightened (Fig 12).

When lifting and placing the outer arches, the arch peak had to engage with the crown plates of the inner arch. With the crane attached and crown plates in contact, a full survey was carried out to ensure all arches were within tolerance.

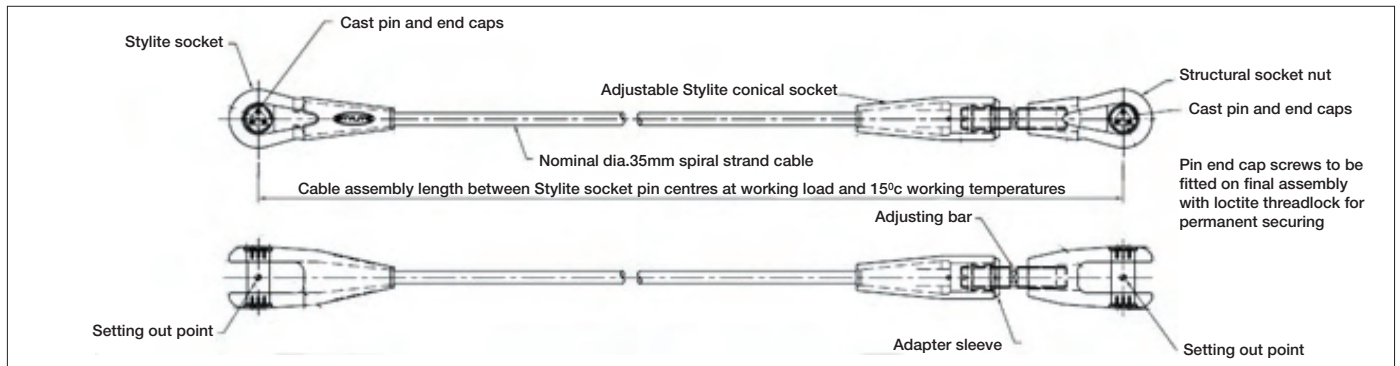
During the second possession, welding of crown plates was followed by non-destructive testing. Then the remainder of deck steelwork was installed, hangers fitted, stairs erected and bolting and painting completed (Fig 13).

Weld testing

Prior to welding, production plates were tested at a UKAS registered laboratory including one transverse tensile test (to cover full plate thickness), one side bend test (to cover full plate thickness), Charpy V notch impact test (one set on weld metal and one set on heat affected zone). Production weld testing comprised non-destructive testing using a combination of ultrasonic and magnetic particle inspection. All testing was carried out within 48h of welding and the acceptance criterion was defined by BS 5400 Part 6. On completion of weld testing, all the joints had the full protection system applied.

Steelwork protective treatment

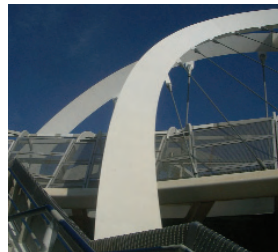
The full paint system comprised blast cleaning surface preparation,



11a



11b



11c

11a,b,c Cable assembly (Courtesy: Bridon Cables)
12a,b Steel arch erection
13 Completed steelwork



12a



12b



13



14

- 14 Bridge lighting
- 15a,b Stainless steel lighting stacks
- 16 Marshalling area seating

metal spraying (aluminium) followed by three coats of brush applied Intercure (total dry film thickness 325µm). Protective system application controls included: monitoring and recording of environmental conditions including steel temperature, ambient temperature and relative humidity. Then, finally, inspection and dry film thickness measurement of each applied coat.

Whilst the paint system was applied at the fabrication yard, a full top coat was roller applied over the whole arch on site.

The corrosion protection system for the cables consisted of using Class A galvanized wires with Metalcoat applied to all internal layers of wires during stranding. Additional corrosion protection was achieved by applying Metalcoat to the exterior cable surface during installation.

Bridge lighting

Lighting on the bridge (Fig 14) comprised functional statutory lighting together with floodlighting to accentuate the bridge's structural form. The functional lighting was provided by columns to match those used in the marshalling area along the central area of the bridge and via linear fluorescent luminaires recessed into the cross members of the canopies to either side of the bridge. A lighting level of 100 lux was provided in the canopied areas and 25 lux provided along the open central area.

The platform below the bridge, which was some 40m wide, was defined as a covered platform. So in accordance Network Rail Standards, illumination levels of 150 lux were adopted for the covered portion and 50 lux for the open areas. Architectural floodlighting was installed to illuminate the four arches using a white LED light with the outer arches being lit from platform level up and the inner arches lit from the bridge deck level up. Care was taken with the positioning of the light fittings at platform level to ensure no possible interference with railway operations. To give a diffused light, blue fluorescent lighting was installed in each section of the structure between the beams and behind the mesh in the location below the deck area canopies.

The staircases from the bridge to the platforms were illuminated utilising a linear fluorescent luminaire fixed adjacent to the mesh side walls at a height of 1100mm. The luminaires follow the profile of the staircase and are of asymmetrical design to illuminate the full width of the treads. The top section of the staircase is open to below and the underside covered with a stainless steel mesh. A blue diffused lighting was provided behind the mesh in the same way as the underside of the bridge. Blue fluorescent lighting was also installed behind the stainless steel mesh to the rear of the benches in the seating areas to provide a diffused light.

Lighting to the marshalling area was provided by column mounted luminaires with a metal halide light source providing an illumination level of 25 lux.

The most prominent feature to the Square is the urban intervention of stainless steel light stacks (Fig 15) set out within a



15a



15b



16

grid pattern which continues over the bridge down to Wembley Triangle. These stacks give an order and scale to the space and provide a focus for the crowds to follow, combining an additional tool of colour coded lighting to assist in channelling the passengers. Trees were considered as an alternative to posts although not considered suitable as the primary means of creating a grid pattern, due to the visibility requirements of a CCTV system. Nevertheless, the design incorporates some trees but they were dispersed, enabling effective CCTV coverage.

It was anticipated that the maximum amount of flexibility should be available in providing access onto the station platforms during event scenarios. Therefore within the Square/marshalling areas, 4.5m high light stacks are positioned within the ground on a grid pattern of 2.5m and 5m, so allowing for different configurations of retractable/removable barriers.

Fixed furniture

In the future, once the land adjoining the Station Square becomes developed, the public square will take on a new *persona*, becoming a hive of social gatherings with bars, restaurants and entertainment spilling out from the buildings. Consequently it was essential to design and position the street furniture in such a way that it was not obvious. Moreover, for a small percentage of the year, the area is used for marshalling crowds so at the same time, the furniture's position can be utilised to aid the marshalling strategy.

To further assist with crowd marshalling, fixed bespoke curved seats (Fig 16) have been positioned to the north allowing on-coming crowds from the stadium to be funnelled through into their correct zones. With trees located at either end of the benches, this makes for a more intimate space within the Square.

Vehicular access onto the bridge is prevented by the provision of stainless steel telescopic, bollards at 1.5m spacings. On non-event days, these are permanently in the raised position (manually operated). Bollards are positioned north of the bridge deck and at the entrance to the pedestrian link on Wembley Hill Road to the south.

Credits

Client: London Development Agency

Architect: Marks Barfield Architects

Structural engineer: Halcrow Group Ltd

Main contractor: BAM Nuttall Ltd (formerly Edmund Nuttall Ltd)

Steelwork supplier: Cleveland Bridge Ltd

Cable assemblies: Bridon Cables