

OVG Manchester

Structural Description - Superstructure Steelwork

BRA-BHE-ZZ-XX-RP-S-0230

0042841

3 July 2020

Revision P02

Revision	Description	Issued by	Date	Checked
P01	Draft Stage 4a	PE	01.05.2020	AP
P02	Stage 4a – Tender	PE	03.07.2020	AP

This report has been prepared for the sole benefit, use and information of OVG Europe Ltd for the purposes set out in the report or instructions commissioning it. The liability of Buro Happold Limited in respect of the information contained in the report will not extend to any third party.

author **Paul Eddleston**

date **03.07.2020**

approved **Andrew Pottinger**

signature



date **03.07.2020**

Contents

1	Introduction	9
1.1	Purpose	9
1.2	Scope of Works for Superstructure Steelwork Contractor	10
1.3	Responsibilities	11
1.4	Secondary Steelwork	13
1.4.1	Façade support elements	14
1.4.2	Miscellaneous secondary structure	15
1.5	Design status	15
1.6	Document status	15
1.7	Document list	15
1.8	References	15
2	General Notes	16
2.1	Loading Criteria	16
2.1.1	Bowl	16
2.1.2	Plant level	16
2.2	Movement joints	16
2.2.1	Joints in floors	16
2.2.2	Joints in bowl steelwork	16
2.3	Interfaces	17
2.3.1	In-situ concrete interfaces, summary	17
2.3.2	In-situ concrete interfaces, typical details	18
2.3.3	Pre-cast Concrete Interfaces	20
2.4	Cladding	21
2.5	Dynamic Testing	21
2.6	Bolted Connections	21
2.7	BIM	21
2.8	Tonnage	22

2.9	Blast	24
2.10	Building Service and Architectural Penetrations	24
3	Superstructure Overview	26
3.1	Structural overview	26
3.2	Dynamic performance	27
3.2.1	Horizontal behaviour	27
3.2.2	Vertical behaviour	27
3.3	Raker splices	27
3.4	Typical bowl details	27
3.4.1	Pre-cast terrace support stools	27
3.4.2	Raker tips	28
3.5	Beam overview	29
3.6	Truss overview	29
3.7	Composite deck	29
3.8	Level 05 Plant Enclosures	29
4	Lower Tier	30
5	Mid-Tier Steelwork	33
5.1	Main raker and bracing structure	33
6	Upper Tier Primary Bowl Structure	34
6.1	Main raker and bracing structure	34
6.2	Steel column and bracing connection to raker	35
7	Surface Protection	36
7.1	Corrosion Protection	36
7.2	Fire Protection	36
7.3	Future Inspections	36
8	Steel Grades	37
8.1	Grade	37
8.2	Sub-grades	37

8.3	Hyzed Steel	37
9	Health & Safety	38
	Appendix A Level 01 Bowl Plan	
	Appendix B Level 05 Plant Enclosures	

Table of Tables

Table 1-1 Design responsibility	12
Table 1-2 Documents referenced within this document	15
Table 2-1 Steel work interfaces with pre-cast elements	20

Table of Figures

Figure 1-1 3D view of Arena primary steelwork	9
Figure 2-1 Superstructure frame Draft Stage 4A tonnages	23
Figure 2-2 Example of L03.5 facade support steel (red) in South East corner Level 03 facade box	24
Figure 3-1 - Typical longitudinal cross-section	26
Figure 3-2 - Typical pre-cast unit to steel details	28
Figure 3-3 - Indicative steel raker tip	28
Figure 3-4 - View of level 05 plant enclosures (in red) from the south east	30
Figure 4-1 Lower-tier bowl arrangement	31
Figure 4-2 - Indicative raker tip detail for lower tier	32
Figure 4-3 - Indicative raker top detail for lower tier, North and South stands	32
Figure 5-1 - Mid-tier bowl arrangement	33
Figure 6-1 - Typical upper tier steelwork	34
Figure 6-2 Typical lateral CHS bracing and steel column connection detail, red showing in-plane CHS bracing	35

1 Introduction

1.1 Purpose

This document has been written to support the information shown on the OVG Manchester structural drawings and to assist the Contractor (and Steelwork Contractor) by providing them with a general understanding of the superstructure steelwork structure. It conveys the structural systems employed, the design constraints, and information on some of the interfaces with other aspects of the structure and the building in general. Any special areas which are considered different from the normal are also highlighted and explained. Where necessary areas of further work and development are noted.

This document should be read in conjunction with the Buro Happold structural drawings, structural Revit model, and other structural documents (as described in Section 1.7); together with the information from the other engineering disciplines and the Architect.

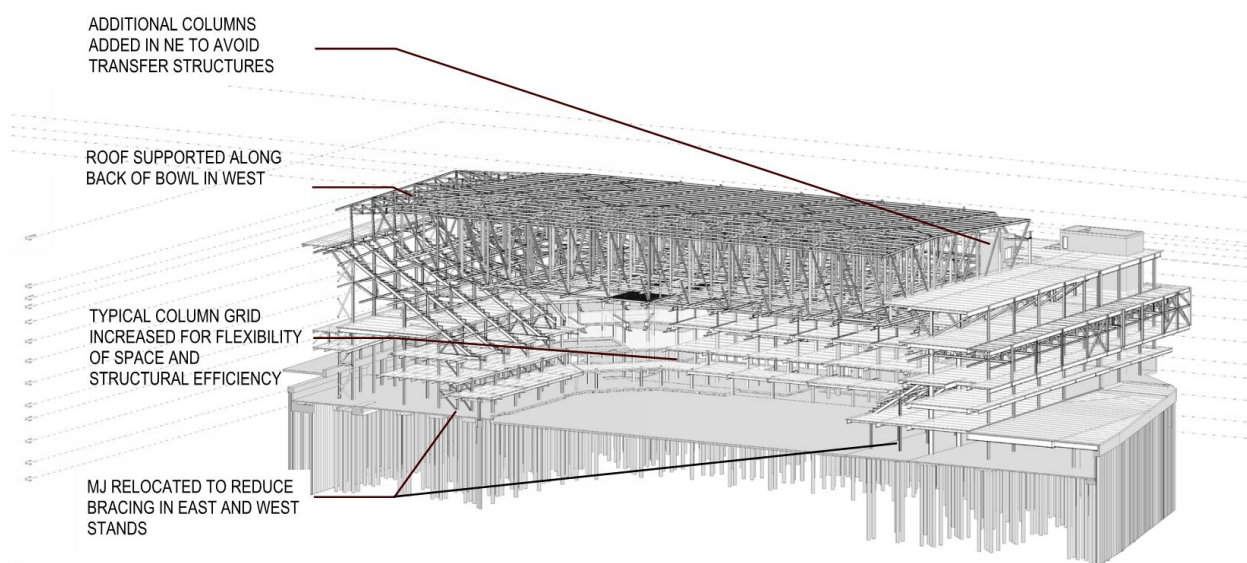


Figure 1-1 3D view of Arena primary steelwork

1.2 Scope of Works for Superstructure Steelwork Contractor

The superstructure primary steelwork package of works is anticipated to include the structural elements listed below (and their joints/connections). This is not an exhaustive list, and provided for assistance purposes only:

- The structural frame above L00
- Rakers
- Stability elements, where not insitu concrete
- Steelwork forming overhangs
- Steelwork above the service yard
- Upper tier back of bowl and vomitory pre-cast support elements including columns, beams and shelf angles to slab and beam edges.
- Riser trimmer steelwork
- All elements within the Buro Happold design will be shown within the Structural Revit model and on the structural drawings.

Refer to BRA-BHE-ZZ-XX-RP-S-0240 for similar information regarding the Arena roof steelwork.

1.3 Responsibilities

The Steelwork Contractor is responsible for the supply and erection of steelwork for the elements defined in Section 1.2, in accordance with this report.

The Steelwork Contractor is to take full responsibility for the quality and workmanship of all elements defined within this report.

Specialist contractor design input will be required for the following:

- An appropriate erection methodology and the checking of all members for temporary erection cases; fully coordinated with the erection methodology and programme for surrounding construction trades.
- Temporary bracing required to resist temporary lateral torsional buckling instability, or any other temporary instability.
- Steelwork joints and connections after member design has been prepared by the Engineer. This work will include design and verification of the local parts of the members connected (i.e. the parts directly affected by the connection detail adopted) as well as gusset and stiffening plates, etc. [The non-embedded components of steel to concrete connections are also the responsibility of the Steelwork Contractor.](#) Details shown on BH drawings are design intent only. Joints visible in the final works are to be cleanly and carefully detailed and agreed with the Engineer.
- Stools and shims on all rakers.
- Corrosion and fire protection paint systems (extent of application and supply to be specified further by the Contractor).
- Holding-down bolt assemblies.
- Profiled metal deck in accordance with the documented performance specification with specific reference to Annex A.4 of BRA-BHE-ZZ-ZZ-SP-S-0110 Structural Steel - Project Specification, loadings documented in BRA-BHE-ZZ-XX-RP-S-0200 Structural Basis of Design Specification and for the steelwork arrangement shown on the structural drawings.
- Local attachments at interfaces with façade and roofing packages.

An outline of design responsibilities relating to the bowl specifically is defined in the table below. A similar table is contained within the precast concrete specification to aid coordination.

Table 1-1 Design responsibility

Design Responsibility			
Designer	Package	Element Design	Connection Design (by Contractor)
Bowl Pre-cast Package Sub-Contractor Designer	Secondary structure: Pre-cast Bowl Package	Terracing units, step blocks, parapet units, end walls, vomitory walls, vomitory bridge units, pre-cast walls and units associated with the upper tier accessible platforms, flat pre-cast units at the back of the bowl, pre-cast composite floor panels acting as interfacing between back of bowl and concourse structure (if required), all other elements of Bowl Pre-cast.	- Connections between bowl pre-cast including steel angles between vomitory walls and units; - Connections in/of pre-cast where connected to primary structure (requires coordination with Main Contractor's Engineer); - Connections in/of pre-cast where connections to bowl metalwork (requires coordination with Main Contractor's Bowl Metalwork Engineer); - Connections in/of bowl pre-cast structure where connected to miscellaneous metalwork (requires coordination with Main Contractor's Miscellaneous Metalwork Engineer); - Additional bowl steelwork supports not shown on the drawings.
Main Contractor's Engineer (Buro Happold)	Primary steelwork + Insitu superstructure concrete, for permanent condition only.	Primary structural support to Bowl Pre-cast: Steel rakers, back-of-bowl steel beams, vomitory support beams, slabs, RC walls and beams, steel trimmers where shown on the drawings.	Connections in/of primary structure where connected to bowl pre-cast (requires coordination with Bowl Pre-cast Package Contractor Designer) – connections to cast in-situ elements such as core walls, shear walls and slab edges.
Steel Fabricator	Steel Frame	- Shims for all rakers; - Stools on rakers.	Connections in/of stools where connected to bowl pre-cast (requires coordination with Bowl Pre-cast Package Contractor Designer);
Miscellaneous Metalwork Package Contractor Designer	Secondary structure: Miscellaneous Metalwork	Metal platforms on pre-cast units	Connections in/of metal platforms structure where connected to bowl pre-cast (requires coordination with Bowl Pre-cast Package Contractor Designer).
Bowl Metalwork Package Contractor Designer	Secondary structure: Bowl Metalwork	- Handrails; - Barriers.	Connections in/of bowl metalwork structure where connected to bowl pre-cast (requires coordination with Bowl Pre-cast Package Contractor Designer).

1.4 Secondary Steelwork

Exact packaging requirements are to be defined by the Employer. Such packaging must also allow for the design (and installation) of secondary steelwork items such as listed below. [Refer to BHE report BRA-BHE-ZZ-XX-RP-S-0202, 0203 & 0250 for preliminary costing advice on some of these items](#)

- Façade steelwork, i.e. steelwork supporting/restraining cladding systems and glazing systems.
- Cold-rolled purlins, sheeting rails and their connections.
- Services support elements and bracketry.
- Riser trimmer steelwork and the like.
- Screen support and restraint steelwork.
- Catwalk and walkway flooring (e.g. perforated planks, durbar plate, grating) – support elements will be shown on Buro Happold drawings.
- Other steel stairs, walkways and access platforms.
- Proprietary and minor metalwork items, such as balustrading, miscellaneous barriers and handrails.
- Miscellaneous plant-room secondary steelwork (e.g. racking and gantries).
- Wind posts to masonry walls and their connections, based on typical requirements and details provided in a laterally loaded masonry performance specification (to be produced by Buro Happold if required).
- Lateral restraint elements required to restrain the top of blockwork walls.
- Lintels, and their connections (if appropriate), based on typical requirements and details provided in a laterally loaded masonry performance specification (to be produced by Buro Happold if required).
- Fall arrest systems and their attachment to the primary structure.
- All steelwork required by the lift manufacturer, including lifting beams and possibly cage lift framing.
- Localised/specific gutter support steelwork.
- Doors, gates and shutters, and their supporting framework.
- External works steel/metal elements such as gates, fences, lampposts, cycle-racks and bollards.

1.4.1 Façade support elements

Below L02 the façade is typically pre-cast concrete. Above L02 it is typically a composite panel system.

Buro Happold are progressing a façade support steelwork scheme to illustrate proposed support and connection back to primary steelwork. [Refer to BHE report BRA-BHE-ZZ-XX-RP-S-0203 for preliminary costing advice.](#)

1.4.2 Miscellaneous secondary structure

Refer to BRA-BHE-ZZ-XX-RP-S-0202 – Secondary structure elements. At RIBA Stage 4a this document is for costing assistance only.

1.5 Design status

This document relates to the following package:

- Steelwork superstructure.

This issue is intended to supplement the Structural Steelwork Material Specification, drawing information, associated documents and structural Revit model. Final setting out information and connection force tables will be provided during Stage 4B to suit the in-progress 4B programme.

1.6 Document status

Revision P02 of this document has been provided as supplementary information alongside the tender information for the steelwork package. The document will be updated and reissued as part of the final construction status information.

Changes made to previous revisions are indicated in blue.

1.7 Document list

This report should be read in conjunction with all other tender and contract documents and drawings for the OVG Manchester Arena project.

Refer to BRA-BHE-ZZ-XX-RP-S-0100 – Structural Design Report for the structural document list.

1.8 References

The documents referenced within this report or of significant relevance to the superstructure steelwork are listed in the table below.

Table 1-2 Documents referenced within this document

Design Standards	
BS EN 1990	Basis of Structural Design
BS EN 1991	Eurocode 1: Actions on Structures
BS EN 1993	Eurocode 3: Design of steel structures
BS EN 1994	Eurocode 4: Design of composite steel and concrete structures
IStructE	Dynamic performance requirements for permanent grandstands subject to crowd action – Recommendations for management, design and assessment

Note: where not listed the latest version of the document should be referenced.

2 General Notes

2.1 Loading Criteria

A detailed breakdown of the loading criteria for the project is presented in BRA-BHE-ZZ-XX-RP-S-0200 Structural Basis of Design. Some of the non-standard loading criteria are outlined below, and the effect on the design of the superstructure steelwork conveyed.

2.1.1 Bowl

The steel bowl structure is designed to resist the vertical loading from the precast units, seating, handrails and crowd loading. The structure is also required to resist 7.5% of the crowd loading as a lateral load to account for the dynamic effects of synchronised movements of the audience during events. This lateral loading is resisted by the bracing elements in the bowl; the loading also induces torsion in the steel rakers which is restrained through moment connections to the circumferential bracing. The rakers within the bowl are stabilised in both lateral directions through the connection towards the back of bowl into the main structural steel frame. Radial forces track through the rakers and into the floor beams and composite slabs which then distribute the force to the cores and other RC stability elements such as shear walls.

2.1.2 Plant level

The outer roof structure supports plant equipment and therefore has a high imposed loading allowance. Refer to loading drawings for applicable loads.

2.2 Movement joints

Movement joints are required to accommodate shrinkage in the superstructure and relieve thermal stresses.

Each self-stable portion is stabilised by a number of large RC cores in each corner and a series of bracing and RC walls. Structural Movements and Tolerances Report RP-S-0500 details the anticipated movements of the structure and movement joint strategy.

2.2.1 Joints in floors

Movement joints in floors allow opening and closing but are tied together in shear (ie parallel to the direction of the joint). The 150thk composite slab is too thin to accommodate standard dowels and so the shear forces must be transferred by the steel beams. The details shown on drawing S-5101 use horizontal shear plates to bridge the joint. Preliminary horizontal shear forces have been provided to aid the contractor in costing this detail. The contractor may wish to suggest alternative detailing options such as dowels or spigots.

2.2.2 Joints in bowl steelwork

Additional movement joints are provided in the terracing at the end of localise bays – refer to bowl general arrangements. This is achieved by slotted connections and PTFE strip on the stools as shown on drawing S-5151. Refer also to section 3.4.1 of this report.

2.3 Interfaces

There are a number of interfaces between different works packages, for example steel to in-situ concrete connections. The Contractor should ensure that the following aspects are addressed when interface details are developed:

1. Coordination – interfaces should be developed through coordination between different package sub-contractors.
2. Detailing – interfaces should be detailed such that they are compatible with each of the packages they interface between.
3. Construction Tolerance – interfaces should account for construction tolerance and provision should be made for adjustment on site where possible.

A summary of the different interfaces between structural steelwork and other packages is given below; further detail is given in the relevant steelwork component section. Notwithstanding the movements and tolerances, fit-up is the responsibility of the Contractor.

2.3.1 In-situ concrete interfaces, summary

The table below outlines primary areas where the steel structure interfaces with the in-situ concrete elements to draw attention for the need for co-ordination between the steelwork contractor and other packages of work. This list will be developed during the detailed design phase to provide further detail. [Refer to Stage 4a detail drawings for information which will be developed further in Stage 4b.](#)

Interface location	Description	Co-ordination required between steelwork and
Column to foundation	Holding down bolts into substructure	In-situ RC substructure and ground floor
Bracing to foundation	Holding down bolts and shear key into substructure	In-situ RC substructure and ground floor

Interface location	Description	Co-ordination required between steelwork and
Beam to RC wall – riser deck support beam	Cast-in bolt socket connectors and steel corbel. (Halfen HUC Universal connection)	In-situ RC, MEP installations
Shelf Angle – riser deck support	Shelf angle bolted to cast-in channel.	In-situ RC, MEP installations
Shelf Angle – precast stair support	Cast-in bolt socket connectors. (Halfen HUC Universal connection) – Invisible connectors as alternative subject to Architect's requirements, TBC with pre-cast stair Contractor	In-situ RC
Beam to RC Core	Cast in embed plates for primary steelwork connection	In-situ RC
Bracing to RC Core	Cast in embed plates for primary steelwork connection	In-situ RC
Composite deck to RC Core	Cast in bolt socket connectors (Halfen channel or similar)	In Situ RC
Prop to RC Core	RC Corbel with sliding bearing for steel	In-Situ RC
Roof to RC Core	Bearing to RC Core lid	In-Situ RC

2.3.2 In-situ concrete interfaces, typical details

The following typical details are considered to apply to the majority of the steel to cast-in connections. It is anticipated that each case will be considered in turn with Contractor input to develop a preferred solution. Connections are detailed to avoid on-site drilling and welding. The connections are detailed to allow some degree of tolerance and adjustability on site, however there may be a requirement for “match-fitting” of steel connection plates, i.e. surveying of cast-in fixing locations and drilling of hols in steel connection plates to suit.

Typical steel beam to RC wall

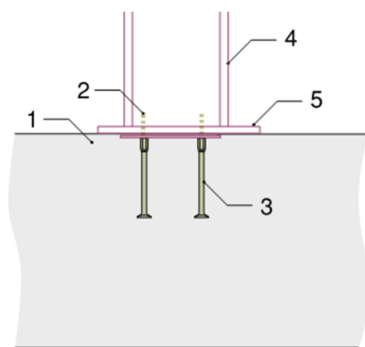
Steel embed plate with shear studs and anchor bars cast into the RC element (stability walls) through attaching to inside face of formwork. Additional reinforcement required to lap cast-in sockets with elements reinforcement. [Refer to detail drawings S-5101 & 5102 and Structural Description Report – In-situ Concrete](#). Where stability loads required to be transferred more substantial anchoring and embed plate arrangement to be developed. Further detail to be provided following detailed design. [Connection forces for embed plates will follow in Stage 4b.](#)

2.3.2.2 Shelf Angle with cast-in channels

Where connections are required to take vertical shear and/or pull out forces only, and the magnitude of connection forces allow, cast-in channels are proposed to provide fixings to the stability walls. [Refer to detail drawings.](#) [Connection forces for embed plates will follow in Stage 4b.](#)

Holding down bolts

Cast-in holding down bolts are to be provided where column bases connect into RC concrete elements.



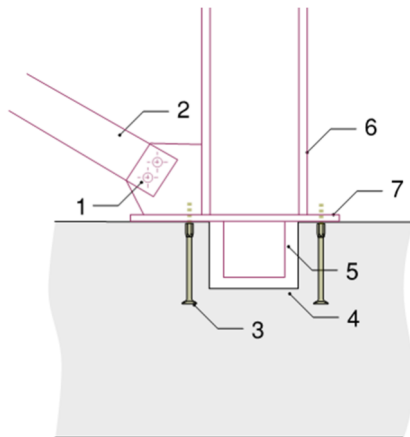
1. RC element
2. Bolts and washers
3. Halfen cast in sockets
4. Steel column
5. Flexible end plate

[Connection forces for baseplates will follow in Stage 4b.](#)

Shear keys

Shear keys are provided where steel to concrete connections require significant lateral shear forces.

[Assume that all baseplates which include bracing elements will require shear keys.](#)



1. Bolted flange plate connection
2. CHS bracing element
3. Holding down bolts
4. Cast void
5. UC shear key
6. Column
7. Flexible end plate with oversized holes

Connection forces for baseplates will follow in Stage 4b

2.3.3 Pre-cast Concrete Interfaces

The table below outlines primary areas where the steel structure interfaces with the pre-cast bowl elements to draw attention for the need for co-ordination between the steel work contractor and other packages of work. [The Steelwork Contractor should refer to BRA-BHE-ZZ-XX-RP-S-0220 – Structural Description – Structural Pre-cast Concrete – Bowl & Stairs](#) which provides additional commentary to those interfaces outlined below.

The items below may develop through detail design [with Package Contractor input](#).

Table 2-1 Steel work interfaces with pre-cast elements

Interface location	Description	Co-ordination required between steelwork and
Lower tier – raker supports to terrace units	Rakers support pre-cast terrace units direct on upper flange and on inverted T integrated into raker.	Pre-cast.
Mid-tier – raker supports to terrace units	Rakers support pre-cast terrace units direct on upper flange and on inverted T integrated into raker.	Pre-cast.
Mid-tier – end raker supports to terrace units and parapet walls	End rakers will require special detailing to enable the end pre-cast terrace unit to span across the width of the raker to the face of the pre-cast parapet wall to the side.	Pre-cast.
Mid-tier – back of bowl	Flat pre-cast units to be supported from rakers/floor beams	Pre-cast
Upper tier– raker supports to terrace units	Typical detail using stools to support precast units on both sides. Front edge support detail has inverted T integrated into raker.	Pre-cast.
Upper tier – vomitory walls to floor beams	Vomitory walls supported on trimming beams and require stool to support. Composite decking required to beams. Where vomitory has pre-cast stairs trimming beams for support and similar stool arrangement required.	Pre-cast
Upper tier– back of bowl structure	Pre-cast elements closing the back of bowl require steel beams and raker support.	Pre-cast

2.4 Cladding

Certain structural steelwork elements are required to support cladding via bracketry and fixings. The bracketry and fixings are to be designed by the façade sub-contractor. Coordination between façade sub-contractor and steel sub-contractor will be required to develop details that are compatible with both structural steelwork and façade designs.

2.5 Dynamic Testing

An allowance should be made for dynamic testing towards the end of construction. This testing, usually undertaken with accelerometers and shaker devices, allows the client and operator to understand the dynamic performance compared to the IStructE publication 'Dynamic performance requirements for permanent grandstands subject to crowd action', 2008. [A specification for this will be produced following the Stage 4a issue.](#)

2.6 Bolted Connections

All bolts in connections to bracing [and truss](#) elements are to be designed to EN 1993-1-8 connection category B, i.e. not allowing the bolt to slip at serviceability limit state using TCBS. In their connection design the Steelwork Contractor should account for behaviours which occur between SLS and ULS.

Other bolts in the superstructure steelwork (as defined by this document) are not required to have non-slip connections.

The corrosion protection of the bolts shall be suitable for the exposure conditions defined in Section 7.1 of this document.

Also refer to the Structural Steel Material Specification

2.7 BIM

The primary steelwork is being modelled in Revit and is in the process of being integrated with the rest of the BIM model – structure, architecture and MEP. It is expected that the Steel Contractor's steelwork model (e.g. in Tekla) will replace the Buro Happold steelwork model at a point to be agreed between Populous, Buro Happold, MEE, Main Contractor and Steelwork Contractor.

2.8 Tonnage

The steel tonnages for the bowl superstructure have been provided in the table below.

Description:

- Tonnages in the below table support the Stage 4A draft on [03/07/20](#). The cost consultant and contractors should refer to these drawings, [reports and specifications](#) for special requirements that will affect cost, e.g. pre-cambering and fabrication.
- 15% allowance is taken for connections throughout – input from steel contractors is welcome to refine these figures.
- No allowance for design development has been included in the below figures, but BHE suggests that allowances for this continue to be made until all design is complete.
- Typical floor plate tonnages have been increased by 5% to allow for detailing in Stage 4, for example to frame risers and floor voids. This should not be considered as a duplication of the overall project design development allowance.

Exclusions

The tonnages provided do not allow for the following items; the cost-consultant and contractors will need to make a separate allowance.

- Roof - tonnages provided separately
- Steel stool stubs supporting terracing from rakers - refer to details on drawing 5151 and notes in this report
- Stiffeners to raker beams to increase bearing and torsional capacity - refer to notes in this report
- Features stairs spanning 22m in the West Stand
- Secondary steelwork - refer to notes in this report
- Façade support steelwork – see Section 1.4.1.
 - [Note that Level 03.5 façade support beams on the north, south and west perimeters \(example in figure below\) have been modelled in the BHE structural revit model, despite their only function being to support façade. The tonnage of these is captured in the façade support steelwork tonnages, not the table below.](#)
- Stiffeners and bracketry required to fix façade to primary steelwork.

Commentary on updates since previous revision

The below table was previously provided in [revision P01 of this report](#). Changes which are considered to have a significant impact on reported tonnages are described below. This is in addition to the effects of on-going coordination and design development.

- Widespread updates to member sizes to reflected detailed Stage 4a design.
- Replacement of ground mezzanine level floor with lower tier raker design. The tonnages in the table below reflect the scheme design discussed in the “lower tier” section of this report and Appendix A.
- Reconfiguration of the Level 05 plant enclosures as discussed later in this report and in Appendix B.
- Remodelling of some Level 03 beams as rakers, eg raker L03-03 on drawing S-3302.
- Reconfiguration of the extent and support to the west stand Level 05 - refer to drawing S-3084.
- Addition of plan trusses behind cores on Levels 02, 03, 03.5 and 04.
- Addition of south-west landscaped podium terracing

Element	Basic Mass	Connection Allowance	Design Detailing Allowance	Total Tonnage
Total	5,586 T			6,612 T
Floor Beams	3,263 T			3,940 T
Level GM	4 T	15%	5%	5 T
Level 01	1,274 T	15%	5%	1,538 T
Level 02	438 T	15%	5%	529 T
Level 03	557 T	15%	5%	673 T
Level 04	486 T	15%	5%	587 T
Level 04.5	54 T	15%	5%	65 T
Level 05	450 T	15%	5%	543 T
Bowl	526 T			605 T
Rakers	457 T	15%	0%	526 T
Bowl Bracing	69 T	15%	0%	79 T
Other Elements	1,797 T			2,067 T
Raker trusses	52 T	15%	0%	60 T
Columns	1,514 T	15%	0%	1,741 T
Vertical bracing	192 T	15%	0%	221 T
Unassigned - back of bowl beams, roof braces	1 T	15%	0%	1 T
Robustness Framing	38 T	15%	0%	44 T

Figure 2-1 Superstructure frame Draft Stage 4A tonnages

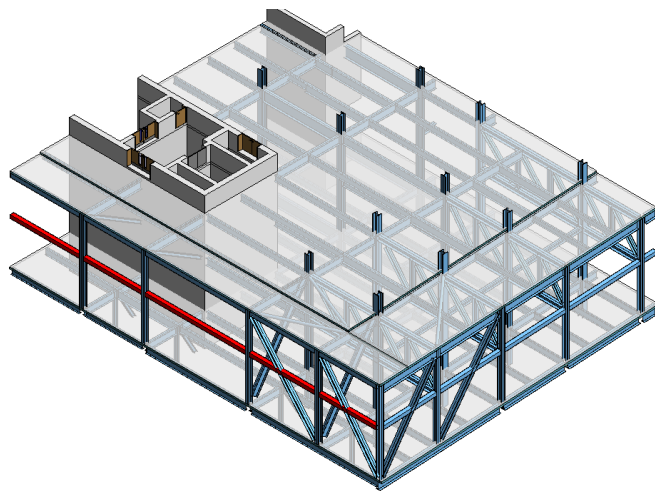


Figure 2-2 Example of L03.5 facade support steel (red) in South East corner Level 03 facade box

2.9 Blast

Issue 3 of 'Project Bradford Blast Vulnerability Assessment' was received from MFD on 6 April 2020. This update reflects the introduction of a full steel frame. No further issues are expected.

BRA-BHE-ZZ-XX-RP-S-0600, Structural Robustness and Systematic Risk Assessment, has been developed to reflect this document and subsequent meetings with OVG. The key impacts on the steel superstructure have been the addition of load distribution steel to the west stand, and an increase in element sizes for overhangs and certain columns.

2.10 Building Service and Architectural Penetrations

Building services are required to pass through elements of the composite deck. Openings are categorised below in accordance with their size, location and type of 'hosting' structure. Large openings in primary structure will be designed and set out on the Construction Information Stage drawings including trimming steel where required. Smaller openings require coordination by the Contractor and review by Buro Happold.

As part of the shop/fabrication drawing process the Contractor is to co-ordinate and finalise BWIC (Builder's Work In Connection) with building services systems and final routing. These shall be submitted to Buro Happold for review and comment.

Indicative penetration locations will be shown on the Buro Happold structural drawings to aid understanding of their distribution.

General allowable penetrations through structural elements are contained in BRA-BHE-XX-XX-DR-S-0005.

Openings in primary structure – Category P10

Openings in composite deck described by any of the following shall be considered as Category P10 Openings:

- not contained by a 300mmx300mm square
- in columns or beams

Category P10 openings are to be shown on the Construction Information Stage drawings. These openings shall be pre-formed during fabrication/placement.

Cast-in openings in composite decking shall be shown on the Concrete sub-contractor's reinforcement drawings, with reinforcement detailed to accommodate the openings (e.g. extra bars around openings, anti-cracking bars, etc.). These shall be submitted to Buro Happold for review and comment.

Openings in primary structure – Category P20

Any openings in primary structure not considered as Category P10 Openings shall be considered as Category P20 Openings.

Category P20 openings will not be included on the Construction Information Stage drawings. The Concrete sub-contractor may choose whether to pre-form (cast-in, fabricate) or post-form (drill, core, cut) these openings. The Concrete sub-contractor shall coordinate Category P20 openings based on MEP installation drawings. These shall be submitted to Buro Happold for review and comment.

Category P20 openings described by any of the following statements should be avoided and may be prohibited by Buro Happold:

- within 300mm of the edge of a wall
- within 1000mm of another opening
- holes in slabs, within 1000mm of a column below

3 Superstructure Overview

The superstructure is a steel frame with composite metal deck floor plates and pre-cast concrete terrace units. This represents a change from traditional reinforced concrete lower levels (as shown at Draft Stage 3), adding value through programme and package simplification based on contractor preference. Furthermore, it has been combined with an increase of radial grid spacing from 6.6m to 8.5m to reduce column and foundation count, improve internal space and optimise the grid for a steel solution.

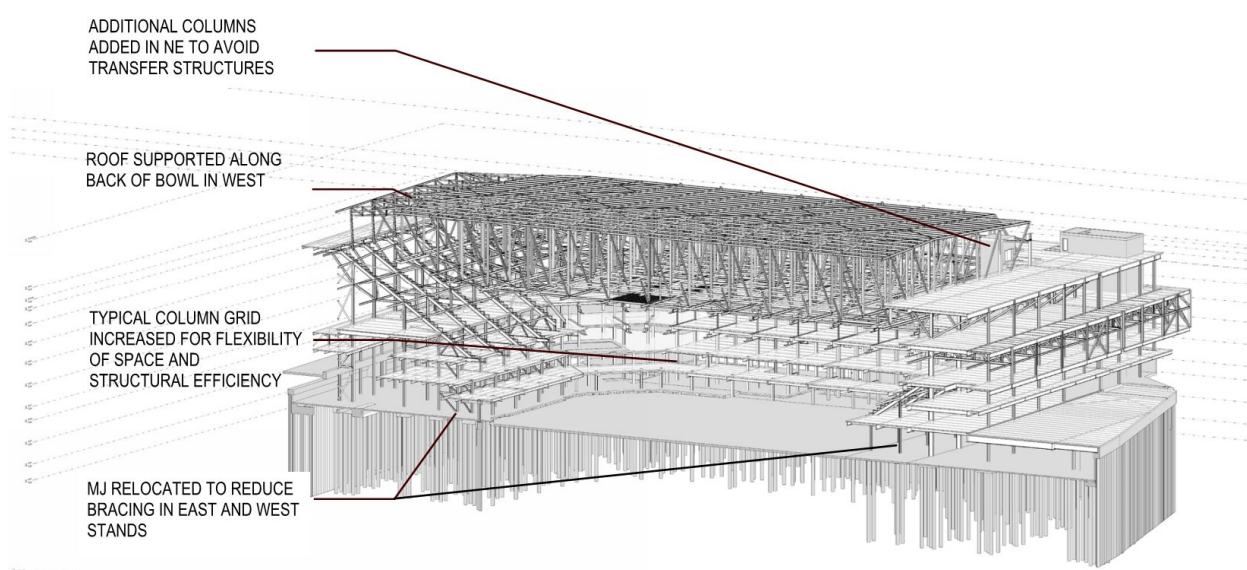


Figure 3-1 - Typical longitudinal cross-section

3.1 Structural overview

The bowl structure is formed by steel rakers supporting pre-cast concrete units spanning circumferentially. The rakers are fabricated I beams, stepping down in depth at their tip to support an inverted tee-section. In-plane bracing transfers lateral forces back to the steel frame and subsequently the RC stability elements and stabilises the rakers rotationally through major moment fixity to stiffener plates. Connection into the RC stability elements is through a combination of the connection between diaphragm floorplate interface and floor beams connected through embed plates to the insitu stability elements.

Steel stools of varying size welded above the raker will support the precast terrace units. The raker spans for North and South are relatively short, and it is proposed standard UB sections be adopted, though these will require web stiffeners and additional bracing for torsion. The east stand has a wider grid spacing of 10.1m and to enable more space behind the stage, a column line has been removed increasing the raker span to 10.4m but shortening the raker cantilever.

In the West Stand, significantly longer spans and interaction with the façade require a series of trussed rakers. This steelwork is visible above the atrium, so the regularity of the geometry is being carefully considered.

3.2 Dynamic performance

Dynamic analysis has been carried out in two parts; global behaviour of each of the individual sections, and local behaviour of each raker. The global behaviour captures the interaction of the slabs with the core/shear walls and the resulting horizontal frequencies associated with each of the sections. The local behaviour of the rakers focuses on the combined vertical frequencies of the precast and rakers. As the detailed design is carried out further details on the behaviour will be documented in this chapter.

3.2.1 Horizontal behaviour

Side to side horizontal excitation is not deemed an issue for grandstands that achieve frequencies above 1.5Hz based on guidance provided in IStructE publication 'Dynamic performance requirements for permanent grandstands subject to crowd action', 2008. The target frequency has been set at 2.0Hz to allow for potential differences between the analysis model and construction.

3.2.2 Vertical behaviour

Dynamic analysis of the bowl has been carried out to establish the fundamental frequencies for each raker and the combined frequency of the precast concrete terrace units and the rakers. The vertical requirement is 6.5Hz for the entire system. For precast unit frequency requirements see BRA-BHE-ZZ-XX-RP-S-0220, Structural Description - Superstructure Precast Concrete Elements.

The sizing of the steel elements of the rakers is predominantly driven by the target frequency and hence element stiffness is critical. This means stress levels are relatively low and below the threshold where fatigue is a concern under cyclical loading and stress.

3.3 Raker splices

The need for splices will be dependent on Contractor advice regarding transportation/preference. Positions of required splices will be developed alongside the Contractor to achieve solutions which maximise their preference whilst ensuring appropriate forces/moments for connection design.

3.4 Typical bowl details

3.4.1 Pre-cast terrace support stools

Steel stools (designed by Steel Contractor) are to be welded to the top of the rakers to support the ends of the pre-cast terrace units. The stools are anticipated to comprise an RHS stub with a welded steel plate above. The plate must be large enough to sit under the beam element of the precast units on both sides to carry the majority of the vertical load and to extend under the slab portion of the units to enable a grouted connection to provide lateral restraint.

The units are to be held in place by means of shear studs and steel dowels bolted to the stools and grouted into the units, see Figure 3-2 for details.

The pre-cast seating units will be 'fixed' connected on one side of the stool with freedom to move laterally on the other in localised positions in the bowl, refer to Bowl GA's. These positions have been considered to limit the length of pre-cast concrete elements 'fixed' together and may develop with the Pre-cast Contractor in Stage 4b. Four global building movement joints require accommodation of larger movements as noted in the detail drawings. This shall be

achieved by having a fixed shear stud on one side of the stool and a threaded bar bolted to the steel plate through a slotted hole on the other side. [Refer to typical details and Movement and Tolerance Report for required movements.](#)

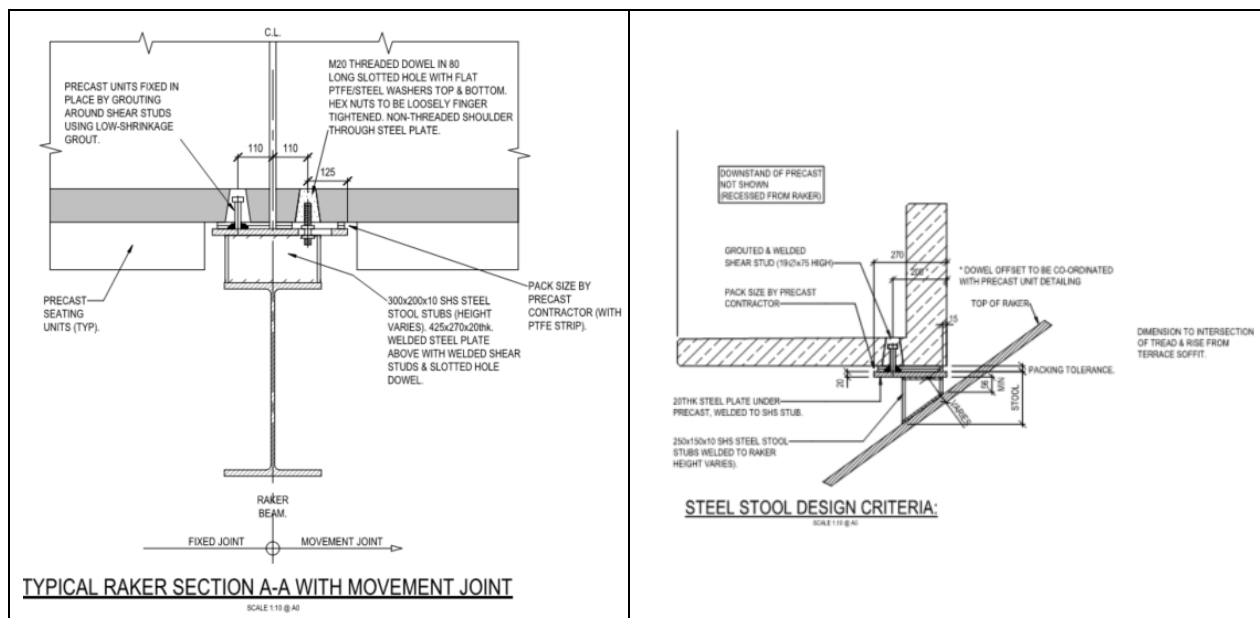


Figure 3-2 - Typical pre-cast unit to steel details

3.4.2 Raker tips

Upturned tee sections will be required at the tip of each mid and upper tier raker, upon which the front precast unit will be seated, to avoid encroaching the space below. This tee will be a bespoke fabricated element.



Figure 3-3 - Indicative steel raker tip

3.5 Beam overview

Allowance should be made for pre-cambering of long span (~18m) fabricated secondary and primary steel beams for the Level 01 podium beams spanning over the service yard.

Beams supporting the podium previously designed as cellular no longer require openings for smoke extract and ventilation. Localised holes within webs may be required to suit MEP and allowance for localised stiffening should be assumed at this stage.

Beams in composite deck areas should have allowance for pairs of 19dia, 95mm high shear studs at 300mm c/c to all beams pending the end of detailed design.

3.6 Truss overview

A number of transfer trusses in the northeast corner and West Stand are required to facilitate the column grid layout. These should be designed as execution class 3 elements and connections made with preloaded bolts.

3.7 Composite deck

Refer to general notes on drawing BRA-BHE-XX-XX-DR-S-0001 for composite deck design. Double span is assumed for construction. An allowance for an additional 20% should be made for additional loose bars required for diaphragm forces and trimming pending detailed design. The deck will be required to act as diaphragm for building stability which may increase reinforcement rates, particularly local to cores and stability walls.

The depth of architectural screeds varies across the floor. To avoid excessive number of steps in the deck, some areas of slab, most notably Level 02, have been set entirely at the lower level. Where screed is not used, concrete finishes are therefore required to bring the top of concrete back to finished floor level. It is envisaged that these should be cast with the structural slab.

3.8 Level 05 Plant Enclosures

Plant enclosures are required at Level 05 in the north-east and south east corners. These enclosures have to be positioned around other plant on Level 05 and so the room layouts rarely align with grid. A number of transfer beams are required at Level 05, often over long spans. The sketch in Appendix B **Error! Reference source not found.** shows the schematic structural design of the plant enclosures, based on the latest architectural layouts.

In both corners the enclosure roofs west of grids N14 and S14 are required to match the profile of the main roof. The boundary between the main roof and the enclosure roofs will require a movement joint which required further detailing and coordination with the architect and façade.

Coordination is on-going to seek a design that minimises the number of transfer beams at Level 05, whilst providing a layout that suits MEP and architectural requirements.

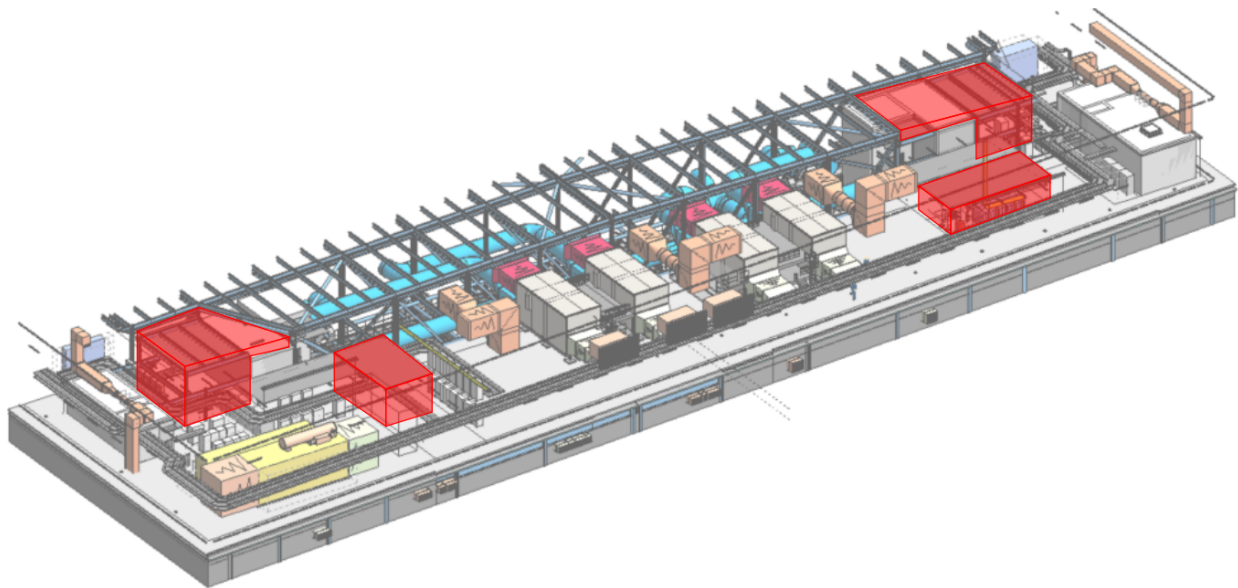


Figure 3-4 - View of level 05 plant enclosures (in red) from the south east

3.9 Level 01 Podium

The Podium is located at L01 and borders the main building on the east, south and west. The podium has a large build up of heavy landscaping and paving, is trafficked by large MUPE and articulated vehicles and also supports a series of planters and water tanks.

Due to the heavy loading and long span above the service yard in the east, circa 18m span fabricated girders are required. Due to the limits on headroom beneath these are to be pre-cambered.

Due to the loading a thick composite deck is to be adopted, with 1.2mm gauge decking.

In the south external terraces are to be framed using a series of raking beams.

At the perimeter to the building the podium is supported on deep fabricated girders with stiffeners. Refer to S-5110 for typical interface details.

At the perimeter of the podium the steel typically bears onto a piled wall capping beam with bearings. Refer to S-5011 for further information.

4 Lower Tier

The lower tier runs around the north, west and south stands and is both partially of fixed seating and partially of retractable seating at ground floor.

The lower tier scheme was part of a Client instructed formal change in RIBA Stage 4a. BH have prioritised co-ordination with the Architect but it requires detailed design before fully complete. At this stage the elements which have been included in the Revit model and GA drawings should be considered placeholders only to assist co-ordination. Detailed design and confirmed member sizing is to be completed following Stage 4a. Indicative arrangement and tonnages are provided in Appendix A of this report to assist the costing exercise.

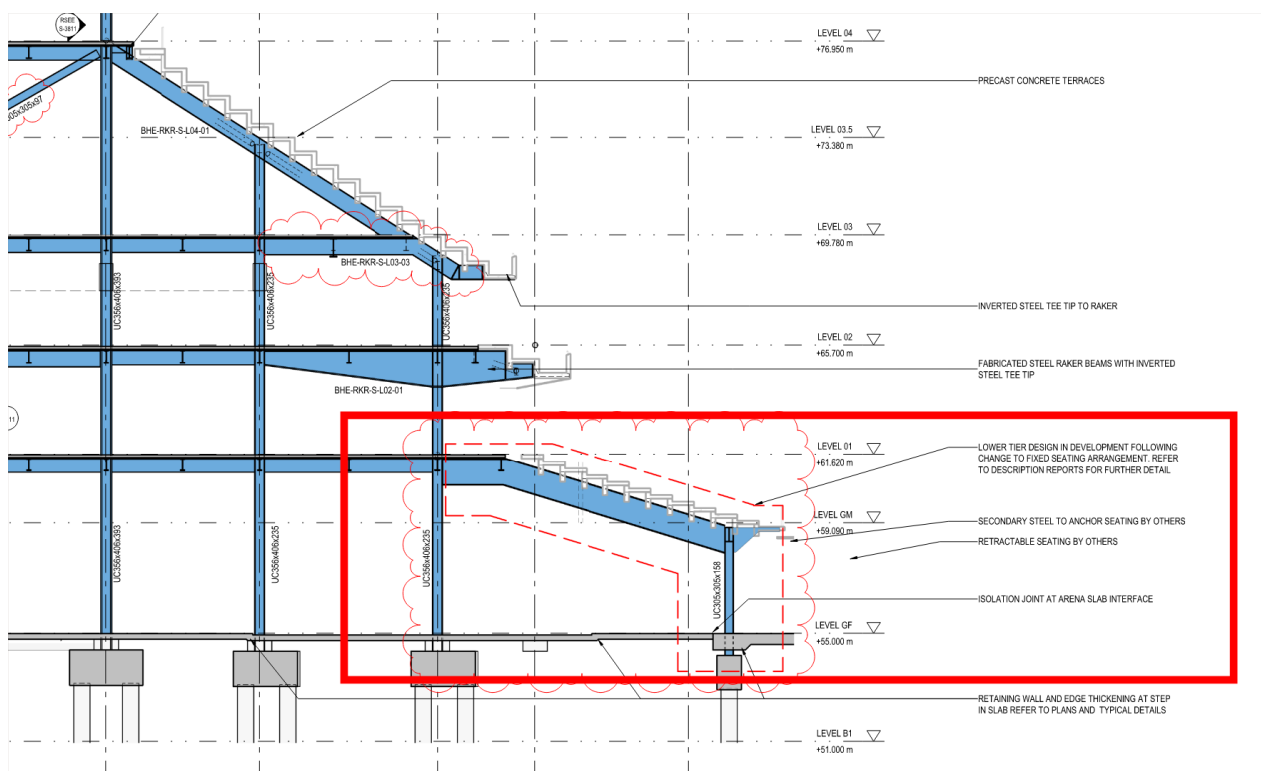


Figure 4-1 Lower-tier bowl arrangement

The last terracing unit has no parapet and so is required to cantilever. Scheming of this terracing unit to achieve the dynamic criteria whilst allowing head height below for the retractable seating requires coordination of details between architects, retractable seating supplier, and pre-cast contractor. A potential arrangement of the raker tip is shown below.

Similarly to the mid and upper tier rakers, it is expected that the lower tier rakers will require web stiffeners at circa 3m spacing.

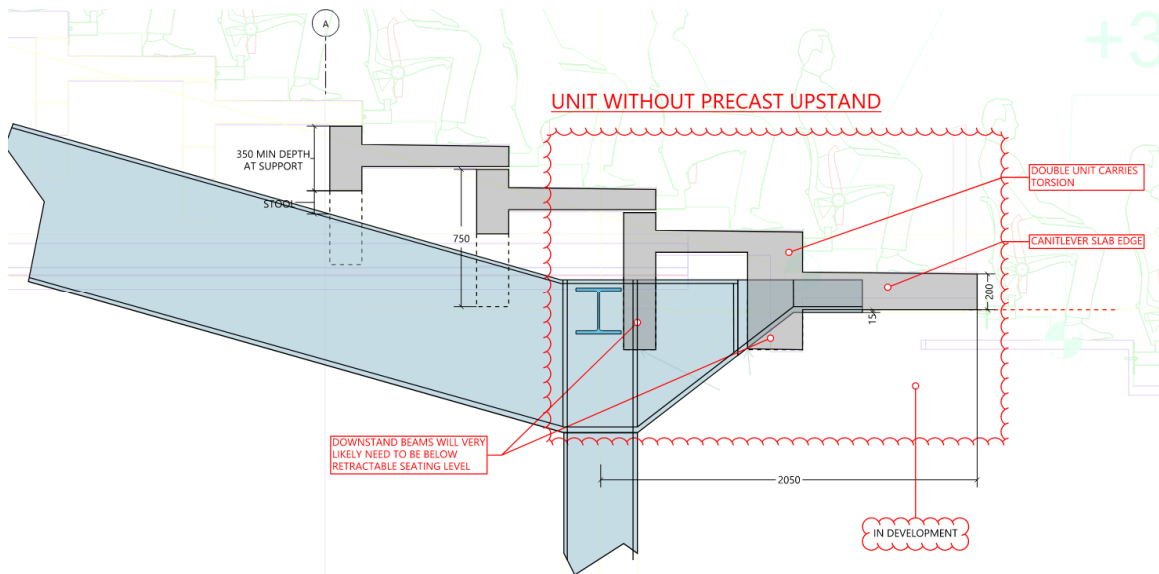


Figure 4-2 - Indicative raker tip detail for lower tier

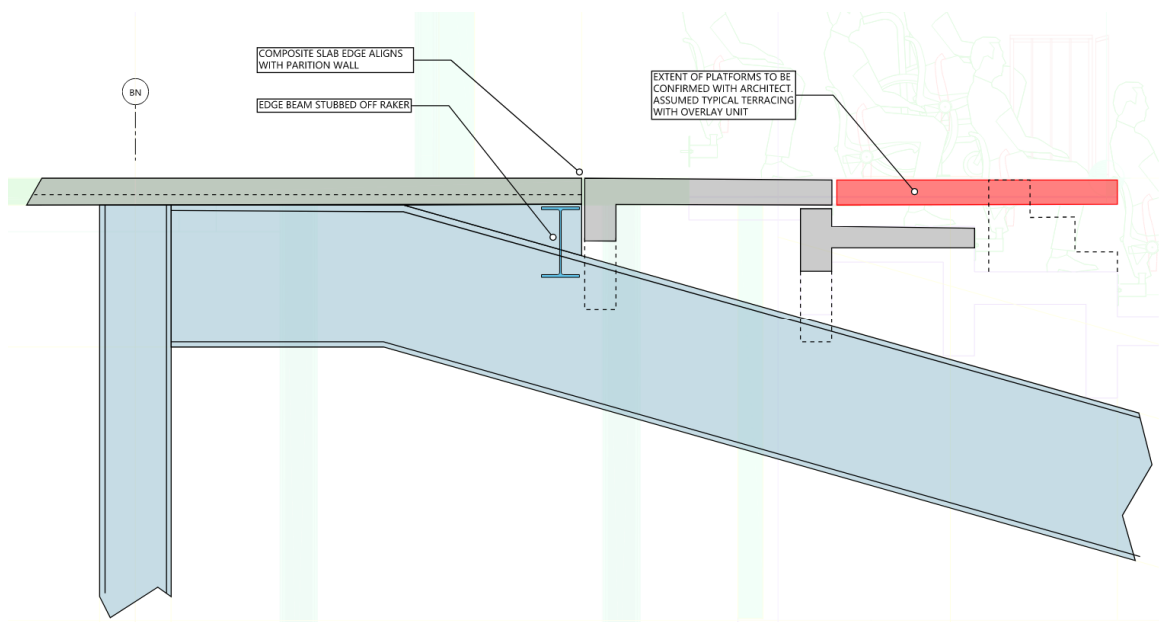


Figure 4-3 - Indicative raker top detail for lower tier, North and South stands

5 Mid-Tier Steelwork

5.1 Main raker and bracing structure

The mid-tier rakers extend from Level L02 and provide seating for the boxes along the inner edge of the North and South stands. To achieve the strength and serviceability requirements the raker will be a tapered fabricated section with maximum depth at the bowl side column. It is envisaged the raker will be fabricated continuously through the column line. This can be developed with the chosen steelwork Contractor.

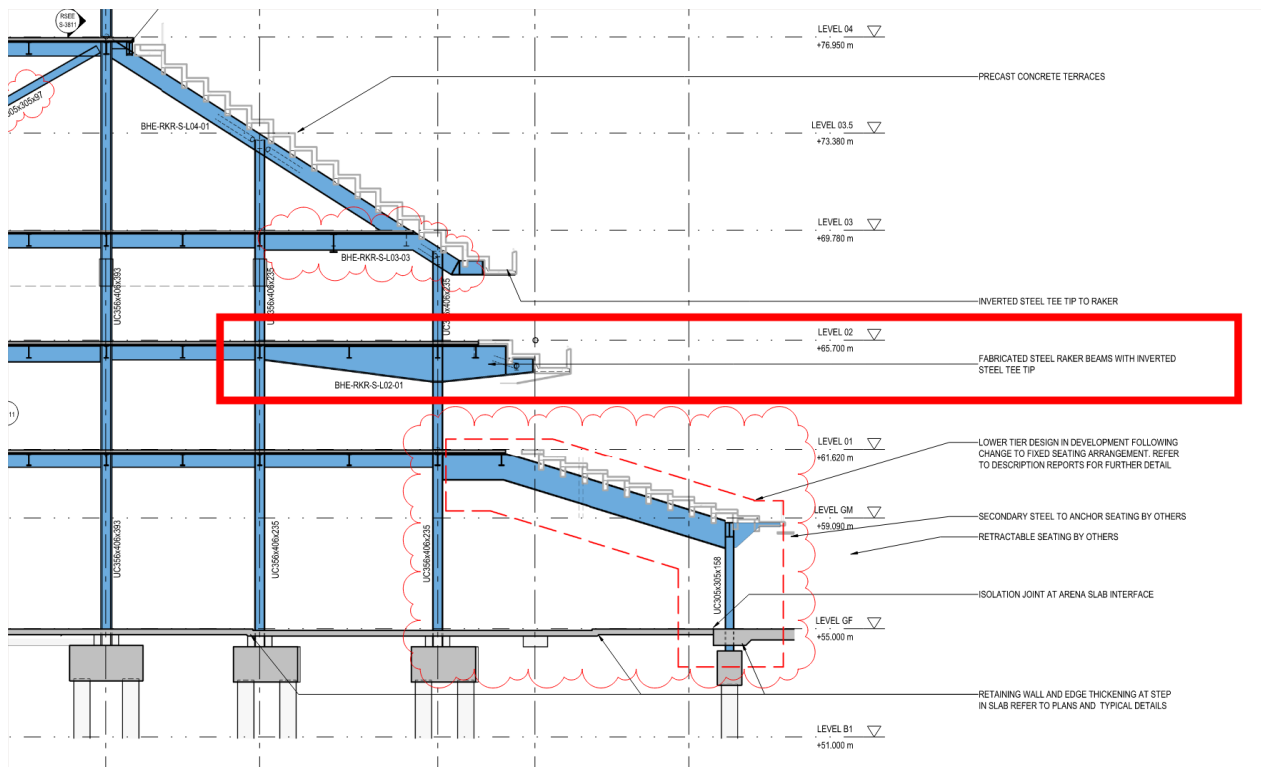


Figure 5-1 - Mid-tier bowl arrangement

Tier bracing will be required in the plane of the rakers for in-plane stability of the bowl. These sections are standard CHS sections.

6 Upper Tier Primary Bowl Structure

6.1 Main raker and bracing structure

The raker spans for North, South and East are relatively short, and it is proposed standard UB sections be adopted, though these will require web stiffeners and additional bracing for torsion. Typically, allowance should be made for web stiffeners at circa 3 metre centres along the rakers, pending the end of detailed design.

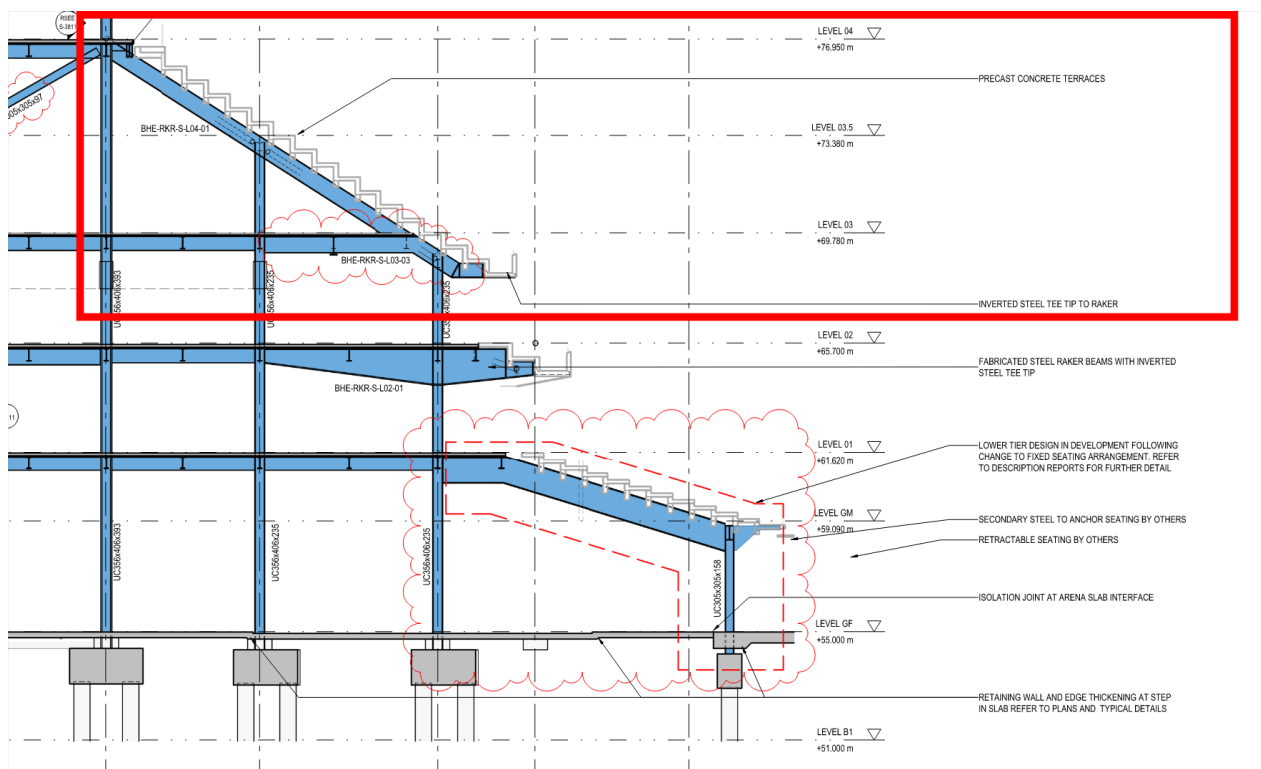
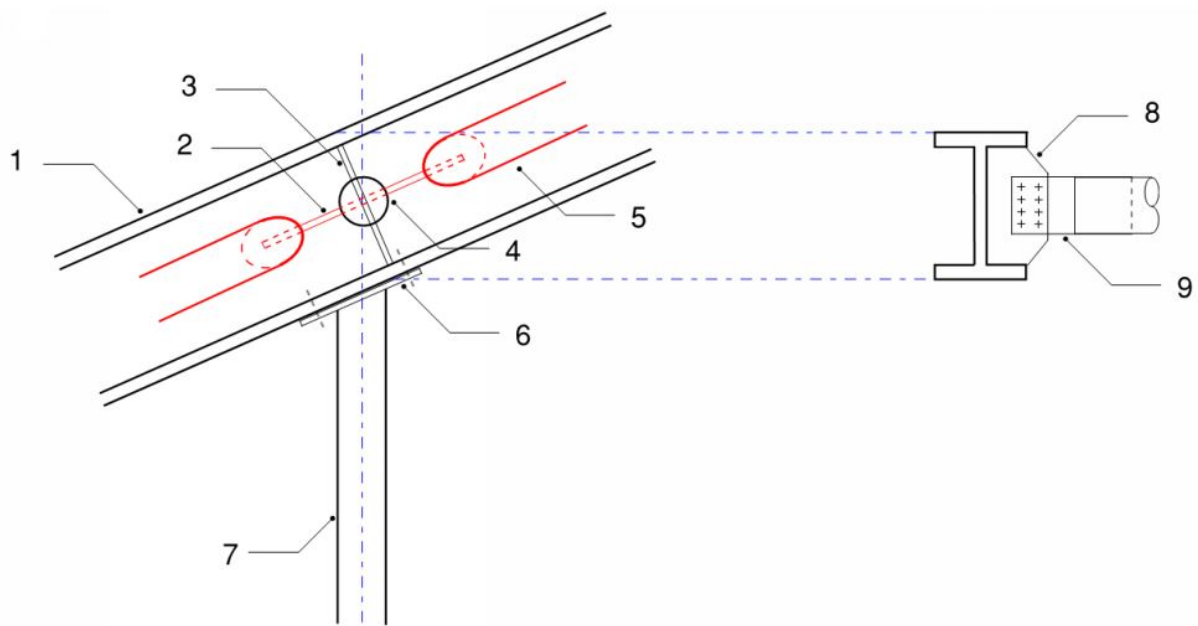


Figure 6-1 - Typical upper tier steelwork

In the West Stand, significantly longer spans and interaction with the façade has resulted in a series of trussed rakers of varying geometry. Fabricated rakers are used to make an efficient section size which is also wide enough to support terracing. Like the North, South and East rakers, allowance should be made for web stiffeners at 3metre centres to provide restraint for torsion.

6.2 Steel column and bracing connection to raker

Lateral (circumferential) CHS bracing connects the rakers at each steel column location or crank point, as shown in Figure 4—5. The bracing connects into a stiffener plate which is orientated perpendicular to the raker, torsionally restraining the rakers and thus requiring the bracing to transfer major moments. In plane CHS bracing (red) provides a means of transferring lateral loads into the RC frame and is situated in every alternate bay.



- | | |
|---|---|
| 1. Welded I section raker | 5. CHS in-plane bracing |
| 2. Stiffener plate to raker within bays containing in plane bracing | 6. End plate connection bolting through flange of raker |
| 3. Stiffener plate perp. to raker and in line with centreline of column | 7. SHS column |
| 4. CHS lateral bracing | 8. Major moment connection |
| | 9. Flange plate bolted connection |

Figure 6-2 Typical lateral CHS bracing and steel column connection detail, red showing in-plane CHS bracing

7 Surface Protection

7.1 Corrosion Protection

For corrosion class refer to the project Steelwork Specification BRA-BHE-ZZ-ZZ-SP-S-0110 Section A.3.

7.2 Fire Protection

Buro Happold have used performance based SFE methods to make an assessment of the thermo-mechanical behaviour of the roof and bowl when exposed to fire. This study will ensure a robust structural behaviour under fire scenarios, and has led to a reduction in the amount/specification of fire protection, whilst considering the life safety aspects as stipulated in the Building Regulations and minimising the constraints on the operability of the venue.

The intumescent paint requirement at tender stage should be based on the drawings within BRA-BHE-ZZ-ZZ-RP-YD-0002 Stage 4A Stage 3 Structural Fire Engineering Assessment, Rev P03.

All superstructure frame primary steelwork (as described in this document and shown on the Buro Happold structural drawings) should be assumed as needing protection for a minimum 90-minute fire resistance unless noted otherwise within this assessment.

The Steelwork Contractor is to ensure that the intumescent paint is compatible with the corrosion protection system(s).

Note that all secondary steelwork elements which aid the stability of non-loadbearing masonry walls (i.e. wind-posts and lintels) must achieve the same fire protection as the associated wall (as will be shown on the Architect's drawings).

7.3 Future Inspections

It is anticipated that the primary steelwork and its protective systems will require spot checks every year, and major inspections every 5 years. The Steelwork Contractor shall advise detailed recommended requirements for the Operation and Maintenance manual for handover to the Client.

8 Steel Grades

8.1 Grade

All primary superstructure steelwork shall be grade S355, hot-rolled UNO.

8.2 Sub-grades

All structural steelwork shall conform to the Buro Happold Structural Steelwork Specification BRA-BHE-ZZ-ZZ-SP-S-110 which should take precedence.

The subgrades shall be determined by the Steel Contractor to match their connection design in accordance with BS EN 1993-1-10. Steel section sizes shall be selected from the relevant British Standard BS-EN sections.

8.3 Hyzed Steel

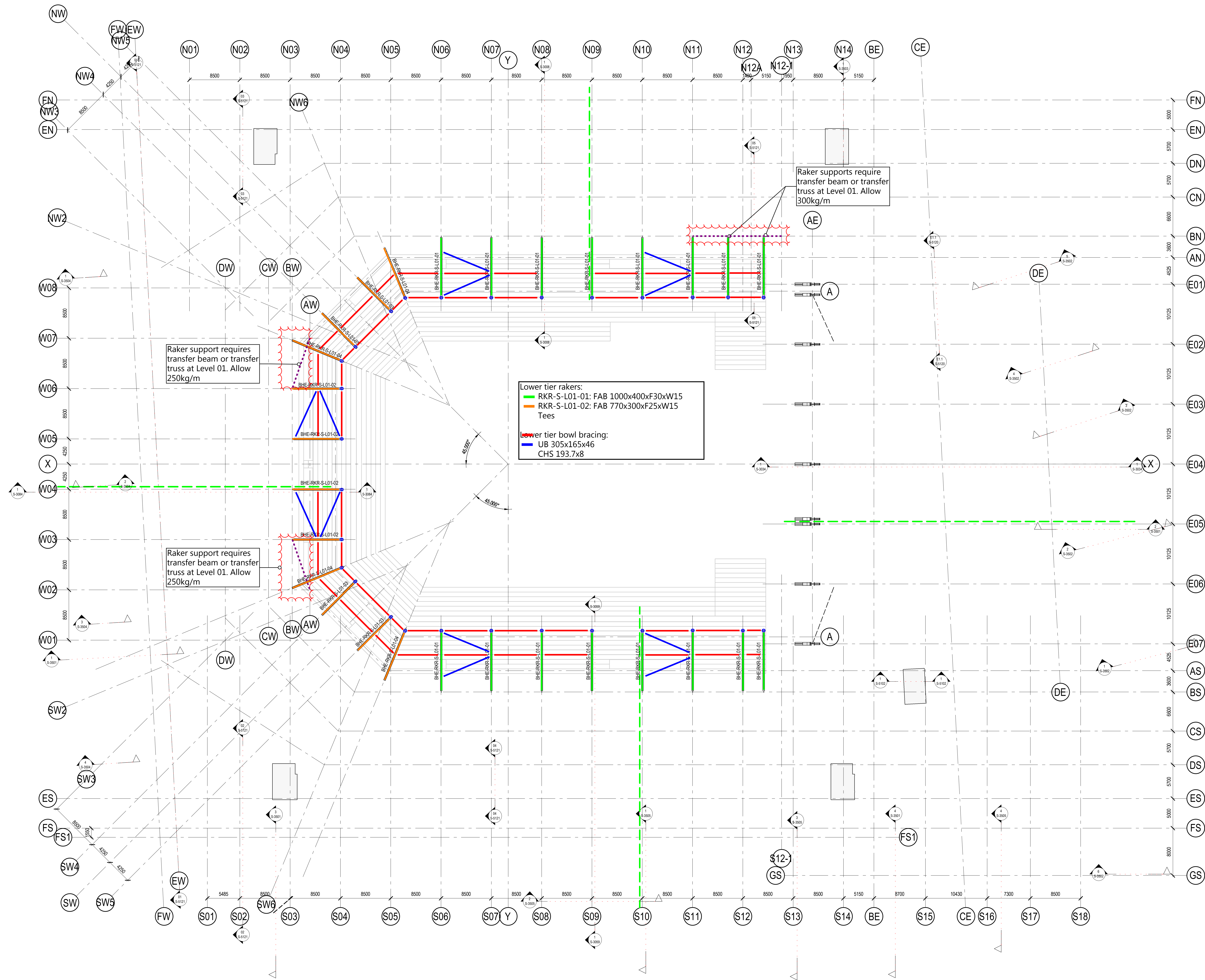
As the Steelwork Contractor develops the connection design proposals it is possible that special grade steel plate is required (such as High-Z steel to guard against lamella tearing in high restraint welded joints). The Steelwork Contractor shall allow for such eventuality based on knowledge of the joint types envisaged.

In areas where there is the potential for lamellar tearing due to through-thickness stresses, hyzed steel should be used.

9 Health & Safety

Refer to the Record of Significant Health & Safety Information (BRA-BHE-ZZ-XX-RP-S-0301)

Appendix A Level 01 Bowl Plan



All rights reserved. This Report and its contents remain the property of the client and are not to be reproduced or used in any form without the prior written consent of the client.

DO NOT SCALE THIS DRAWING.

Suitability Code (as defined in ISO 19650-2:2018)

Work in Progress (WIP)

S0 - Initial Status

Shared (Non-Contractual)

S1 - Suitable for co-ordination

S2 - Suitable for information

S3 - Suitable for review & comment

S4 - Suitable for stage approval

S5 - Withdrawn

S6 - Suitable for PIM authorisation

S7 - Suitable for AIM authorisation

Published (Contractual)

A1, A2, A3, Etc - Authorised and accepted

B1, B2, B3, Etc. - Partial sign-off (with comments)

Published (AIM Acceptance)

CR - As constructed record document

SAFETY HEALTH AND ENVIRONMENTAL INFORMATION

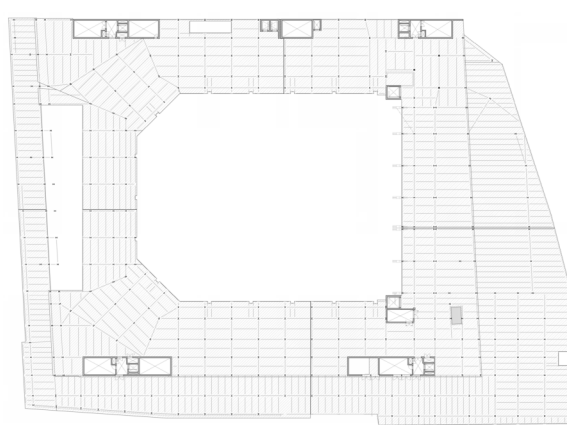
IN ADDITION TO THE HAZARD INFORMATION NORMALLY ASSOCIATED WITH THE TYPES OF WORK, THE FOLLOWING INFORMATION IS PROVIDED FOR YOUR INFORMATION.

CONSTRUCTION

MAINTENANCE/CONSTRUCTION

COMMISSIONING/OPERATION

Key Plan



Notes

BUROHAPPOLD
ENGINEERING

STRUCTURES

Job Title:
OVG MANCHESTER ARENA

Job Number:
042841

Sketch Title/Number:
BRA-BHE-XX-XX-SK-S-2013
Level 01 Bowl Plan

Date:
01/07/20

Initials:
JF

Appendix B Level 05 Plant Enclosures



Paul Eddleston
Buro Happold Limited
Camden Mill
Lower Bristol Road
Bath
BA2 3DQ
UK

T: +44 (0)1225 320 600

F: +44 (0)870 787 4148

Email: Paul.Eddleston@BuroHappold.com