BURO HAPPOLD

OVG Manchester

Structural Description - In-Situ Concrete

BRA-BHE-ZZ-XX-RP-S-0210

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3 July 2020

Revision P02

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Contents

1 Introduction 9

1.1 Purpose 9

1.2 Scope of Works for Concrete Sub-contractor 10

1.3 Responsibilities 10

1.4 Secondary Structures 10

1.5 Design status 11

1.6 Document status 11

1.7 Document list 11

1.8 References 11

2 General Notes 12

2.1 Loading Criteria 12

2.1.1 Event Floor Loading 12

2.1.2 Forklift Loading 12

2.1.3 Articulated Truck Loading 12

2.1.4 Façade Maintenance Equipment (MEWPs) 12

2.2 Reinforcement 12

2.2.1 Reinforcement Estimates 13

2.2.2 Reinforcement Intent Drawings 14

2.3 Visual Concrete 14

2.3.1 Floor Finishes 14

2.4 Shrinkage 15

2.5 Primary Steel to Concrete Interfaces 15

2.6 Fixings 16

2.7 Building Service and Architectural Penetrations 17

2.7.1 Openings in primary structure – Category P10 17

2.7.2 Openings in primary structure – Category P20 17

2.8 Plant Bases 18

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3 Substructure Overview 19

3.1 Substructure 19

3.2 Introduction 19

3.2.1 Ground Conditions and Site Constraints 19

3.2.2 Site Constraints 20

3.2.3 Ground Gas 20

3.2.4 Localised water pressure underground slab 21

3.3 Retaining walls 21

3.3.1 Category of Basement 21

3.3.2 Ground Water Level and retaining solutions 23

3.3.3 Retaining walls – proposed solutions 24

3.3.4 Sequencing 24

3.4 Foundations 24

3.4.1 Differences between Arena and Etihad South Stand site 24

3.4.2 Estimated Pile Capacities 25

3.4.3 Proposed Pile Type and Layout 25

3.4.4 Pile Cut Off Levels 25

3.5 Ground bearing slabs 26

3.6 Joint Locations 26

4 Superstructure Overview 27

4.1 Stability Systems 27

4.2 Stability load path 28

4.3 Core Walls 28

4.3.1 Wall Thickenings 29

4.3.2 Wall Projections 29

4.3.3 Floor beam connections 30

4.3.4 Cantilevered façade box support 31

4.3.5 Level 05 Cantilever Support 34

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4.4 Composite Metal Deck Slabs 34

5 Health & Safety 35

Appendix A Core Reinforcement Intent Sketches

Appendix B Ground Floor Reinforcement Allowances

Appendix C L00 Slab Design for Secondary Consolidation

Appendix D Ground Slab Tolerances

Appendix E Ground Slab Joints

Table of Tables

Table 1—1 Documents referenced within this document 11

Table 2—1 RC & Primary steelwork interfaces 16

Table 2-2 Anticipated post-fixed items 17

Table 3-1 Grade of Basements – Extract from Concrete Basements – Guidance on the design and construction of concrete basement structures (The Concrete Centre) 22

Table 3-2 Types of water retaining structure and acceptability 23

Table of Figures

Figure 1—1 Main structural components 9

Figure 2—1 Element Volumes for Reinforcement Estimates 14

Figure 2—2 Shrinkage Reinforcement at Construction Joints 15

Figure 4—1 Movement joints and stability elements 27

Figure 4—2 Large shaft for precast stair & landings 29

Figure 4—3 Support of eccentric floor beams 29

Figure 4—4 Typical floor beam cast-in plate connection 31

Figure 4—5 Typical cross section through core highlighting cantilevered massings to external face 31

Figure 4—6 Struts 32

Figure 4—7 Strut and ties provided on plan to take horizontal force back to return walls 32

Figure 4—8 Typical strut bearing (section) 33

Figure 4—9 Plan strut and tie connection to return wall (plan view) 33

Figure 4—10 Level 05 cantilevers aligned with return core walls 34

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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 preferred Contractor (and Concrete sub-contractor) by providing them with a general understanding of the structure. It conveys the structural systems employed, the design constraints, and the 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 together with the information from the other engineering disciplines and the Architect.

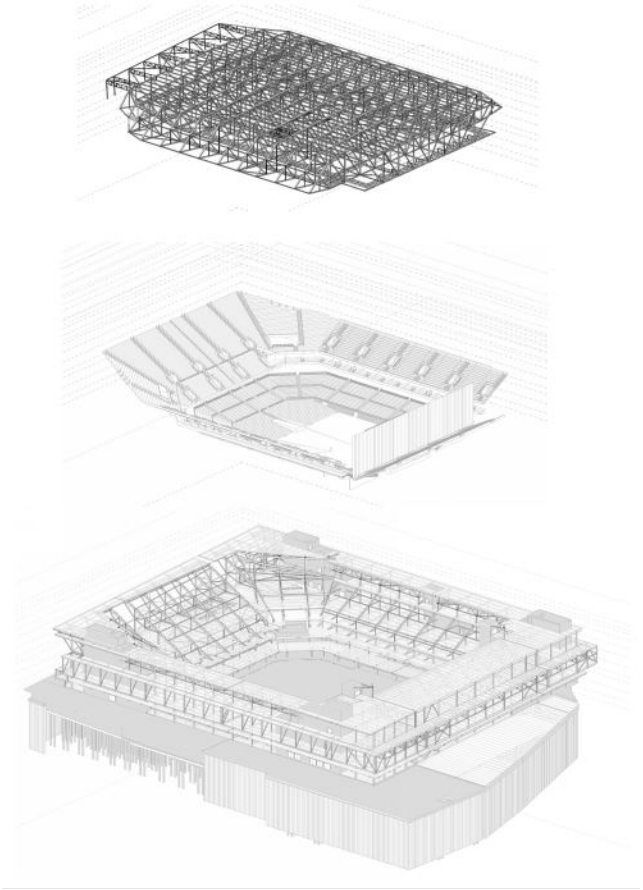


Figure 1—1 Main structural components

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1.2 Scope of Works for Concrete Sub-contractor

The concrete package of works is anticipated to include the structural elements listed below. This is not an exhaustive list, and is provided for assistance purposes only:

- Reinforced concrete (RC) pile caps and ground beams
- RC and mass concrete spread foundations
- RC embedded and traditional retaining wall structures
- RC trench structures
- RC ground floor structures
- Build-up beneath the ground floor slab, including sub-base, blinding, gas & vapour proof membrane, below slab insulation, joints and sealants.
- RC cores
- RC walls
- Cast-in elements.

All elements within the Buro Happold design are shown within the Structural Revit model and on the structural drawings.

1.3 Responsibilities

The Concrete sub-contractor is to take full responsibility for the quality and workmanship of all elements defined within this document.

1.4 Secondary Structures

Exact packaging requirements are to be defined by the Employer. Such packaging must also allow for the design of secondary structure items such as the following:

- External works foundations to gates, fences, lampposts, signage, benches and the like.
- Foundations to hostile vehicle mitigation bollards and other bollards.
- Foundations to cycle-racks.
- Planters, where not shown on the Buro Happold drawings.
- Foundations to external terracing between the building and the Ashton Canal.

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1.5 Design status

This document relates to the following packages:

- In-situ Concrete Substructure and Ground Floor
- In-situ Concrete Superstructure

This issue is intended to supplement the Structural Concrete 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.

Refer to the following documents regarding precast concrete elements:

- BRA-BHE-ZZ-XX-RP-S-0220 - Structural Description – Structural Precast Concrete – Bowl and Stairs

1.6 Document status

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

Changes made to this document from the previous revision have been indicated in blue text.

1.7 Document list

This report should be read in conjunction with all other tender and contract documents and drawings for the OVG Manchester project. Refer to BRA-BHE-ZZ-XX-RP-S-0100.

1.8 References

The documents referenced within this report are listed in the table below.

Table 1—1 Documents referenced within this document

Design Standards	
BS EN 1990	Basis of Structural Design
BS EN 1991	Eurocode 1: Actions on Structures
BS EN 1992	Eurocode 2: Design of 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.

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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 Specification*, this should be read in conjunction with the Structural Loading Plans. Some of the more onerous loading criteria are outlined below, and their effect on the in-situ concrete structure design discussed

2.1.1 Event Floor Loading

The event floor has been designed to resist an area load of 30kN/m^2 to allow high versatility of use; such as a swimming pool or earth mounds for motocross events. The slab is also designed for localised point loads from forklifts, articulated lorries, stage supports and retractable seating.

2.1.2 Forklift Loading

The event floor, service yard, retractable seating stores and podium are designed for a forklift point load, as required by the Operator. Refer to BRA-BHE-ZZ-XX-RP-S-0200 *Structural Basis of Design Specification*.

2.1.3 Articulated Truck Loading

Articulated truck point loads should be considered for the service yard, event floor. Refer to BRA-BHE-ZZ-XX-RP-S-0200 *Structural Basis of Design Specification*.

2.1.4 Façade Maintenance Equipment (MEWPs)

To maintain and replace the facades MEWPs are likely to be required in certain locations. It is assumed all façade cleaning access MEWPs will be positioned on the podium or on surrounding ground level surfaces. Refer to BRA-BHE-ZZ-XX-RP-S-0200 *Structural Basis of Design Specification*.

2.2 Reinforcement

The Concrete sub-contractor is responsible for the production of all reinforcement placement drawings and bar bending schedules.

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2.2.1 Reinforcement Estimates

Reinforcement estimate are shown below:

Element	Reinforcement estimate [kg/m^3]
Piles	200
Pile-caps	125
Core Bases	175
Ground Beams	175
Ground Floor Façade Edge Thickening	175
200 Ground Slab	2xA393 *
400 Ground Slab	125 *
300 Ground Slab	2xA393 *
Event Floor Edge Thickening	150
Liner Wall Edge Thickening	125
Core Walls	150
Shear Walls	150
Non-stability Walls	125
Retaining Walls	175
Water-retaining Liner Walls	250

* Allowances in typical areas. Please refer to Appendix B for further allowances to be made

The allowances do not include weights of cast-in items such as brackets, façade fixings, etc. Estimates take into account reasonable and efficient detailing and scheduling methods using long bars to minimise splices.

Reinforcement quantities are to be based on the concrete volumes for each element as identified below, with some volumes of concrete being included two or three times, as shown in Figure 2—1.

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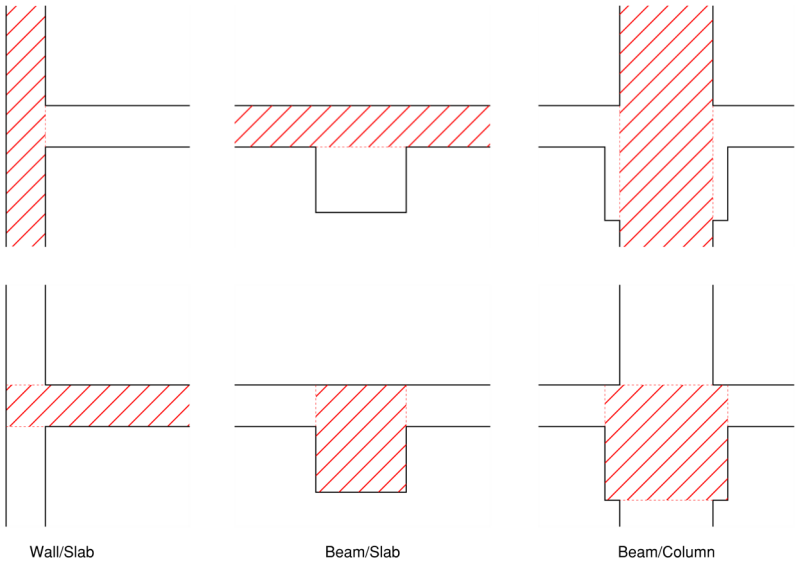


Figure 2—1 Element Volumes for Reinforcement Estimates

2.2.2 Reinforcement Intent Drawings

Reinforcement intent drawings will be developed during Stage 4B.

2.3 Visual Concrete

Exposed concrete walls are to be high quality, smooth, with uniform texture and colouration, to a Plain or Special finish standard.

It is likely that a number of areas of floor slab will adopt polished concrete as a final finish. This is to be reviewed with the Architect.

The extents and specification for areas of visual concrete will ultimately be defined in the architects' drawings and specifications. The concrete mix design used to achieve the visual requirements should still comply with the structural requirements set out in the Buro Happold structural concrete specification BRA-BHE-ZZ-ZZ-SP-S-0100.

2.3.1 Floor Finishes

Floor finishes are to be confirmed by the architects. It is likely there will be several categories.

- Finishes in corporate spaces;
- Finishes in plant rooms;
- Finishes in concourse spaces.

Transitions between these zones may require steps in the slabs in certain locations. The concrete mix design used to achieve the finish requirements should still comply with the structural requirements set out in the Buro Happold structural concrete specification BRA-BHE-ZZ-ZZ-SP-S-0100.

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The depth of architectural screeds varies across the floor. To avoid excessive number of steps in composite 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

2.4 Shrinkage

Slab and wall elements are designed to limit crack widths due to concrete shrinkage. The guidance in CIRIA C766 *Early-age thermal crack control in concrete* has been used to determine reinforcement requirements which are included in the rebar estimates given in this report.

There is to be additional reinforcement provided adjacent to construction joints. This is to control cracking induced by the restraint provided by the previously cast slab. The below diagram indicates the extents of the additional reinforcement:

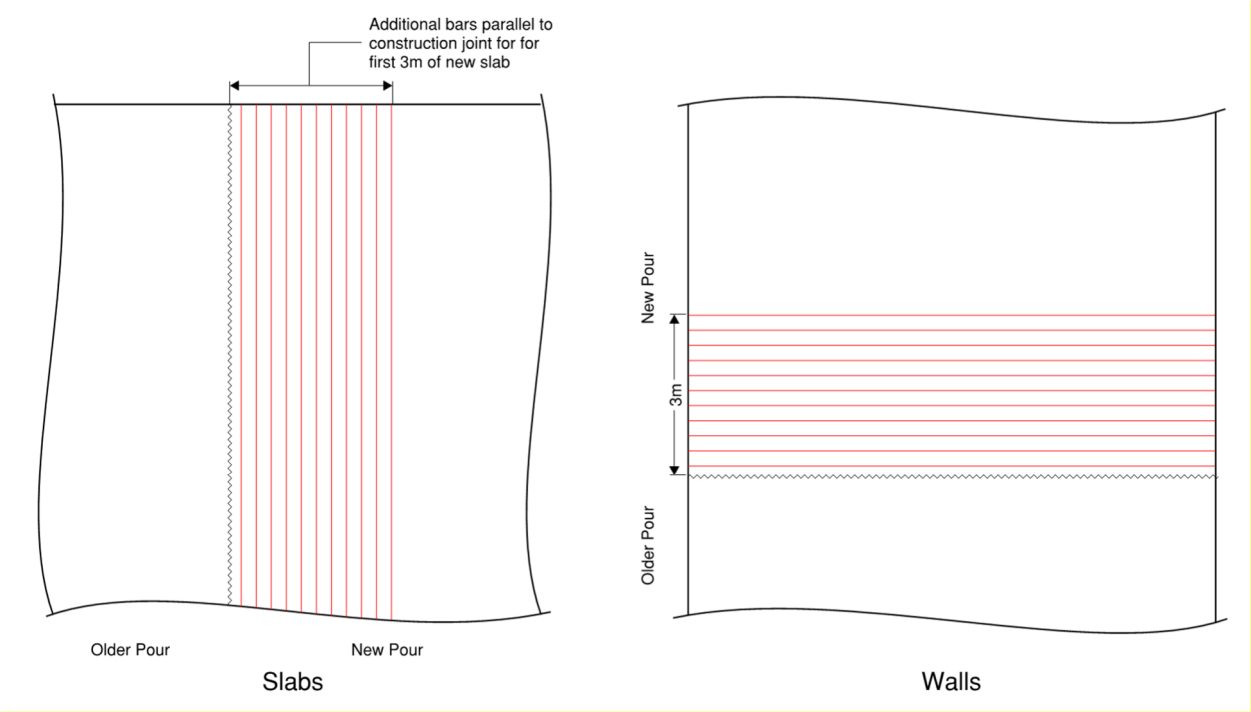


Figure 2—2 Shrinkage Reinforcement at Construction Joints

For the ground slabs, the Contractor should develop the construction pour sequence to minimise stress caused by early age thermal effects and shrinkage for review by Buro Happold. This pour sequence should include a sequential pour layout (not hit and miss); with pour aspect ratios in line with the Buro Happold concrete specification. This pour sequence must be agreed with Buro Happold prior to construction.

2.5 Primary Steel to Concrete Interfaces

The design requires a series of primary steel to concrete connections, as summarised in the table below. This will be added to during the detailed design stage. The Concrete Contractor should thus allow for coordination and liaison with the Steelwork Contractor to facilitate site installation.

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Note that proprietary assemblies and embedded plates may require localised reductions to aggregate grade below the maximum 20mm defined in the concrete specification.

Table 2—1 RC & Primary steelwork interfaces

Examples of components Interfacing with Primary Concrete Structure	Type of Connection
Connection to primary steel - frame steelwork	Detailed design TBC but likely for number of cast-in embed plates to suit connections between steel floor beams and stability elements to RC stability elements. Refer to details on drawing S-5102.
Connection to primary steel – Hanger framing steelwork	Refer to 4.3.4 for additional commentary on these elements
Connection to primary steel – primary steelwork columns	HD assembly and baseplate co-ordination with substructure. Detailed design to be developed with steel fabricator but likely for both regular HD bolt assemblies and requirements for shear key provision where necessary. Joint to capping beam along Joe Mercer Way to allow degree of rotation. Detail design to be developed with steel fabricator. Refer to details.
Support to primary steel – perimeter retaining wall	Sliding bearing support co-ordination with capping beam and steel podium structure. Detailed design to be developed with steelwork fabricator. Refer to details.
Support to primary steel – buttress walls	Sliding bearing support co-ordination with buttress walls and steel podium structure. Detailed design to be developed with steelwork fabricator. Refer to details.

2.6 Fixings

The design of fixings for architectural and building service items and their fixing mechanisms is the responsibility of the designer of the item requiring fixing.

- Heavyweight fixings, e.g. cladding fixings and all cast-in fixings, may have a significant impact on the design of the permanent structure. Coordination and agreement are required between the designer of the fixings and Buro Happold on the locations and details of all heavyweight fixings to the primary structure, and the forces they exert on the primary structure.
- Lightweight fixings, e.g. fixings for electrical trunking, ceiling panels etc., have a negligible effect on the primary structure, and do not require the involvement of Buro Happold.

In general, it is intended that fittings, fixtures, services and finishes (particularly cladding connections, balustrading and barriers) are connected to concrete using pre-coordinated cast-in fixings as opposed to post-drilled fixings.

The following items are expected to be post-fixed.

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Table 2-2 Anticipated post-fixed items

Examples of components Interfacing with Primary Concrete Structure	Suggested Type of Fixing
Wind-posts for non-load bearing masonry	Post-fixed connections by secondary steelwork contractor.
Ceilings and internal finishes	Post-fixed connections.
Suspended services	Post-fixed connections.

Note that above tables are not exhaustive lists and are presented to provide an indication of the anticipated cast-in and post-fixed items, refer to architectural, services and lighting drawings for scope and extent of these components.

2.7 Building Service and Architectural Penetrations

Building services are required to pass through elements of the in-situ reinforced concrete structure (including 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. 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 guidance on allowable penetrations through structural elements are contained in BRA-BHE-XX-XX-DR-S-0005.

2.7.1 Openings in primary structure – Category P10

Openings in in-situ reinforced concrete structure 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 reinforced concrete 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.

2.7.2 Openings in primary structure – Category P20

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

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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

2.8 Plant Bases

Suitable allowances should be made for plant bases, which will be shown on the developing MEP drawings.

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3 Substructure Overview

3.1 Substructure

This section describes the ground floor structure and the foundations.

3.2 Introduction

This section has been written to support the information shown on the Structural drawings and to assist the Contractor (and Concrete sub-contractor) by providing them with a general understanding of the concrete substructure. It conveys the structural systems employed, the design constraints, and the 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 is done to help provide information to others to help guide costing by others and to highlight key issues that will also need to be considered by others for programme (design programme, planning programme and construction programme). As such this section:

- Describes the key important site and constraint issues affecting groundworks, foundation and substructure design: such as stratigraphy, groundwater level and impact of coal seams
- Makes reference to further Buro Happold design documents
- Describes the proposed engineering design solutions for basement perimeter walls and foundations
- Gives information on the basement grade and recommendations on how the required level of water resistance can be achieved. Final waterproofing design responsibility lies with the contractor concrete subcontractor.
- States the uncertainties and unknowns associated with the site. There is good historical information in many sources; however, there are still a number of unknowns (as is commonly the case with most sites). Certain risks can be mitigated through the knowledge gained in the Ground Investigation (GI).

Reference should be made to latest issue Structural drawings for key design information at this stage.

3.2.1 Ground Conditions and Site Constraints

For detailed information on the existing site conditions, reference should be made to the Geoenvironmental and Geotechnical Interpretative report BRA-BHE-XX-XX-RP-CG-004. What follows summarises some of the most relevant information and relates it to the earthworks and substructure packages.

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3.2.2 Site Constraints

- There is an easement around some electrical infrastructure in the south east of the site. The basement footprint of the building has been adjusted to respect this;
- There are two known mineshafts on the site, in the north and north east. These mineshafts have been remediated but there are restrictions around piling in the vicinity. The foundation design has been adjusted to account for these. Further information on the mineshafts can be found in the Buro Happold Coal Mining Risk Assessment BRA-BHE-XX-XX-RP-CG-0005. There is believed to be a third possible shaft that was not located in the Site Investigation but is referred to in some historical documentation. Due care and attention should be taken in this area when carrying out site works.
- Due to the number of below-ground obstructions discovered during GI site works, it is suggested that sheet piling is not used for the perimeter retaining walls, even with a pre-bore, as it may not penetrate in a number of areas, particularly to east of site. Further, unless special measures are taken, due to the proximity of services to the boundary with Alan Turing Way, sheet piling to this location may not be acceptable. As a result, a contiguous piled wall solution has been provided as a more robust engineering solution given variability of the ground and proximity to existing services, structures and boundaries.
- Along the western edge of the site here is a timber crib wall which supports Joe Mercer Way. It is recommended that measures are taken to ensure installation of the western line of piles adjacent to this wall does not compromise the stability or condition of the wall, through the use of guide structures or by survey prior to piling. The wall has been set out based on survey information received from BAM, it is recommended that prior to installation of the contiguous piled wall the footing is exposed along the full length and a full location and condition survey undertaken for review and approval by the Structural Engineer and Design Team. Appropriate time should be allowed in the programme for this.
- To the south of the site the existing Forge Lane Bridge is located with services including High Voltage Electricity cables and 400mm gas pipe in close proximity. The footings to the bridge are also at a higher level to the canal towpath. Enabling /temporary works, landscaping and structural works in this area will need to be sequenced and coordinated to avoid undermining the bridge foundations or causing damage to existing services.

3.2.3 Ground Gas

The historical land uses and geological setting of the site are relevant to the consideration of potential sources of gas. Ground gas monitoring was undertaken on a total of 11 locations following the site investigation.

- The calculated GSV for CO2 and CH4 (concentrations x flow rate) have been arithmetically determined as Characteristic Situation 1. However, in accordance with CIRIA C665 it is recommended the Characteristic Situation is increased to Characteristic Situation 2 due to the multiple elevated concentrations of CH4 and C02 above the typical maximum value for CS1 (1% and 5%, respectively) and the depleted oxygen concentrations recorded.
- The data described above are considered reliable, having been obtained from an appropriate number of installations, with appropriate response zones and under varying atmospheric conditions. The data are generally very consistent, both within the data set itself and with the observed ground conditions. The soil descriptions and the nature of the gas regime provide good lines of evidence that the source of the gas is the Made Ground, the nature and extent of which has been well defined by the recent ground investigations.

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An allowance for ground gas protection measures suitable for Characteristic Situation 2 should be considered in the cost plan (i.e. installation of a gas proof membrane).

3.2.4 Localised water pressure underground slab

The design water level is well below the underside of the ground floor slab, however perched groundwater is present in the made ground and the potential for this should be considered in the ground slab detailing. The material beneath the ground slab should be fee drainage to prevent any localised build-up of water pressure on the ground floor slab. It is suggested that a free draining, low fines material is used for the piling mat, allowing for a minimum thickness of 200mm underneath the slab. In the temporary condition, this will help the management of surface water due to rain in the excavation.

3.3 Retaining walls

The development will include a single storey basement cut into the slope of the site, retaining up to 7m height at a maximum in the South East corner of the site.

Refer to BRA-BHE-ZZ-XX-RP-S-0400 which has been prepared to provide an overview and summary of excavation support requirements for the basement of the OVG Manchester Arena. The purpose of this report is to set out the design basis and design assumptions for the respective retaining walls required for excavation support for construction of the basement.

3.3.1 Category of Basement

In order to provide an appropriate design solution for the retaining structure, the category of basement must be specified by the Client. The client has instructed a Grade 3 basement will be required. This will provide a space appropriate for habitation.

It is proposed that two layers of protection are provided; watertight concrete and an externally applied membrane. Please refer to *Below Ground Waterproofing Performance Specification* for further details (BRA-BHE-XX-XX-SP-S-0200).

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Table 3-1 Grade of Basements – Extract from Concrete Basements – Guidance on the design and construction of concrete basement structures (The Concrete Centre)

Grade of basement*	Usage*	Performance level*	Performance level**			
			Relative humidity**	Dampness	Wetness	Temperature
1 (Basic utility)	Car parking Plant rooms (excluding electrical equipment) Workshops	Some leakage and damp areas tolerable. Local drainage may be required	> 65% normal UK external range	Visible damp patches may be acceptable	Minor seepage may be acceptable	Car parks: atmospheric Workshops: 15–29°C Mechanical plant rooms: 32°C max. at ceiling level
2 (Better utility)	Workshops and plant rooms requiring drier environment than Grade 1 Retail storage	No water penetration but damp areas tolerable*** dependent on the intended use. Ventilation may be required to control condensation	35–50%	No visible damp patches***, construction fabric to contain less than air dry moisture content	None acceptable	Retail storage: 15°C max. Electrical plant rooms: 42°C max.
3 (Habitable)	Ventilated residential and commercial areas including offices restaurants etc. Leisure centres	Dry environment. No water penetration. Additional ventilation, dehumidification or air conditioning appropriate to intended use	40–60% 55–60% for restaurants in summer	None acceptable. Active measures to control internal humidity may be necessary	None acceptable	Offices: 21–25°C Residential: 18–22°C Leisure centres - Spectators: 18°C - Squash courts: 10°C - Changing rooms: 22°C - Swimming pools: 24–29°C Restaurants: 18–25°C Kitchens: 29°C max.
(4)** **(Special)**	Archives Landmark buildings and stores requiring controlled environment	Totally dry environment. Requires ventilation, dehumidification or air conditioning appropriate to intended use	50% for art storage >40% for microfilms and tapes 35% for books	Active measures to control internal humidity probably essential	None acceptable	Art storage: 18–22°C Book archives: 13–18°C

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3.3.2 Ground Water Level and retaining solutions

A design groundwater level of 41m OD has been identified.

Perched water has been noted in wells in the made ground. The flow of this water will need to be controlled during construction by either excluding from the basement or by active control with pumping.

At this stage, considering the classifications shown in Table 3-2 the water table risk classification is taken 'Variable' due to perched water within the Made Ground.

A bonded waterproofing membrane is proposed to the perimeter. As a gas membrane is also required, there are a number of products available that can fulfil both functions.

Table 3-2 Types of water retaining structure and acceptability

Water table Classification[a]		Types of water-resisting construction			
		Type A (barrier protection)	Type B (structurally integral protection)		Type C (drained protection)
			Piled wall	RC wall to BS EN 1992	
Risk associated with water table: Low ↓ High	**Low**	Acceptable	Acceptable	Acceptable	Acceptable
	Variable	May be acceptable if 'variable' Classification is due to surface water: seek manufacturers' advice	Acceptable where a) the piled wall is directly accessible for repair and maintenance from inside the structure or b) the piled wall is combined with a fully bonded waterproofing membrane or c) the piled wall is faced with a concrete wall to BS EN 1992	Acceptable	Acceptable
	High	May prove acceptable where a concrete wall to BS EN 1992 is used or where cementitious renders or coatings are used		Acceptable	Acceptable

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3.3.3 Retaining walls – proposed solutions

Refer to Retaining *Wall Design Assumptions* (BRA-BHE-ZZ-XX-RP-S-0400) for proposed solutions.

3.3.4 Sequencing

Refer to Retaining *Wall Design Assumptions* (BRA-BHE-ZZ-XX-RP-S-0400) for assumed sequencing.

3.4 Foundations

Piled foundations are required due to the size and type of the structure and the ground conditions. The following geotechnical risks have been identified:

- The Coal Measures mudstone and number of coal seams on the site are likely to present a constraint to the foundation design.
- Two worked shafts present on site have been avoided in the foundation design, with an 8m exclusion zone. A further 'ghost' shaft may be present on site. If located, the foundation design may require local adjustment. The location of the worked shafts is shown on the foundation plan. The contractor will need to confirm the location of these on site as excavation work commences. Refer to Geotechnical Interpretative Report (BRA-BHE-XX-XX-RP-CG-004) and Coal Mining Risk Assessment (BRA-BHE-XX-XX-RP-CG-0005).
- The foundation layout has been designed to accommodate all known easement zones, assuming that the drain running through the middle of the site can be abandoned.
- Buried obstructions identified in previous ground investigations may impact the type of pile being installed and influence the programme
- The Ashton Canal is in close proximity to the proposed development and certain conditions may be required of the works as a result.

3.4.1 Differences between Arena and Etihad South Stand site

Whilst nearby geographically, there are several key differences between the site of the Etihad South Stand expansion and the OVG Manchester site.

- Whilst Coal Measures are located beneath the Etihad South Stand, there are far more coal seams running beneath the OVG Manchester site. The depth of these seams will govern the length of piles required.
- A potential fault line has been identified on the site. This will likely lead to a greater degree of weathering in the zone surrounding the fault.
- There is a much greater depth of made ground on the OVG Manchester site compared to the Etihad South Stand expansion site.
- There are remediated mine shafts present on site. These will need to be bridged by any foundations. A further mine shaft was believed to be a duplicate item on a plan, but this needs to be confirmed to ensure it is not present on site.
- Existing drainage and electrical infrastructure and associate easements will need to be considered

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- Below ground obstructions were found on site when it was last remediated, and in places these obstructions were removed. However, there is the possibility that further ground obstructions exist. Further significant obstructions were encountered at depth in the GI site works.

3.4.2 Estimated Pile Capacities

For pile capacity (working capacity) estimates refer to Buro Happold substructure drawing information and pile schedule.

3.4.3 Proposed Pile Type and Layout

Piles supporting the arena superstructure and roof are proposed as a split of Continuous Flight Auger (CFA) and Rotary bored, in advance of detailed pile design and rig selection by a piling sub-contractor. The precise split is to be determined by the piling contractor.

Rotary bored piling is the most suitable/flexible technique in these conditions. It is critical to avoid founding directly in a coal seam, and only with rotary bored piling is it possible to verify the condition at the toe of the pile.

The use of CFA piles in place of rotary bored is permissible and to contractor choice, pending satisfactory rig selection and trials/testing in accordance with the BH specification. There is a significant risk of locations where CFA piling will not be possible due to below-ground concrete obstructions and hard sandstone/ironstone strata which the rig may not be able to penetrate. In addition, the length of bore within rock will be at the upper limit of what all but the most powerful CFA rigs can achieve.

Risks can be mitigated to an extent by keeping a standby rotary rig available for use in these locations. Ultimately, the pile design and choice are by the contractor and a mix of pile types may be the strategy that best balances technical and commercial requirements.

The depth of coal seams across the site varies meaning final pile lengths may vary, so an estimate of pile length to avoid founding within a seam has to be made. We consider that on average, 25m long piles are likely to terminate below the lowest seam and provide sufficient capacity. The final lengths and reinforcement will be determined by the piling contractor during Stage 4B, taking account of the variable depths of coal underlying the site and the vertical and horizontal pile loads from the pile schedule.

3.4.4 Pile Cut Off Levels

It is assumed that all piles within the perimeter retaining walls except for the buttress wall piles and piles they are connected to will have an installation level no greater than 2m above the pile cut off level. Refer structural drawings for design assumptions on piles installed from high level.

It is assumed that the buttress wall piles are installed at high level with the capping beam piles. The buttress wall pile caps will need to be oversized accordingly to account for plan tolerances due to higher pile installation level, pile cap details will be developed during Stage 4. Refer to Retaining *Wall Design Assumptions* (BRA-BHE-ZZ-XX-RP-S-0400) for assumed sequencing.

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3.5 Ground bearing slabs

The event floor is key to providing a flexible space suitable for a myriad of different shows and productions. Events such as Motocross and Monster Trucks can impart huge loads on to the event floor slab, which will need to be considered. The design criteria for this area is a uniform load of 3 tonnes per m2 or individual point loads of 10 tonnes.

A 400mm thick ground bearing slab will transfer and distribute these large loads to the ground. Outside the event floor the slab thickness is reduced to 200mm, except directly under the loading bay, which will be 300mm thick.

There is possibility of notable creep settlement over time in the made ground. The depths and levels of made ground vary significantly across site with the worst case conditions in terms of long term settlement occurring to the north and west of the site. The slab has been designed in these areas as partially spanning to take into account possible effects of long term settlement. Refer to Appendix C for design note on slab design for secondary consolidation.

Key requirements:

- The event floor slab structures must be monolithic except for construction joints.
- Thickenings will be required around the perimeter of the slab and below heavily loaded walls and stairs. A dowelled edge thickening is required to the event floor slab to limit differential settlement.
- The design assumes no floor screeds are required and therefore the floor slab must be power float finished to high tolerances.
- A deep edge thickening is required to support the precast concrete cladding to the north and west of the ground slab.
- Provide slip membrane on concrete or sand blinding under all ground slabs.
- Provide isolation joints around superstructure columns and walls. Allowance for anti-crack bars should be made around isolation joints.
- Saw cut joint locations are under development. Final numbers and locations to be developed during Stage 4B
- Provide Ancon DSD dowelled free movement joints, 1No per meter, at max. 40mm CTRS each way, typically, with closer centres in trucking areas.
- Joints within arena floor and trafficked areas to be provided with armour protection e.g. Permaban Eclipse or equal.
- All joints to be filled with polyurethane sealant e.g. Sikaflex or equal in accordance with architect's details.
- The zones of retractable seating have tighter than normal tolerances for flatness and level (Refer to Appendix D for Tolerance Class Assumptions).

3.6 Joint Locations

The final jointing strategy for the ground floor slab will be developed during Stage 4B. Refer to Appendix E for proposed jointing strategy.

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4 Superstructure Overview

4.1 Stability Systems

Movement joints are required to accommodate shrinkage in the superstructure and relieve thermal stresses. The current movement joint strategy and key vertical stability elements are illustrated in Figure 4—1 below. Each quadrant is stabilised by RC cores in each corner and a series of steel braced bays and RC walls. Connections across joints should allow for horizontal movement in the perpendicular direction to the joint. The vertical shears and horizontal shears in the parallel direction to the joint are transferred across the quadrants. A shear transmitting plate system is proposed through the steelwork connections, since the deck is too shallow to accommodate normal RC dowel systems.

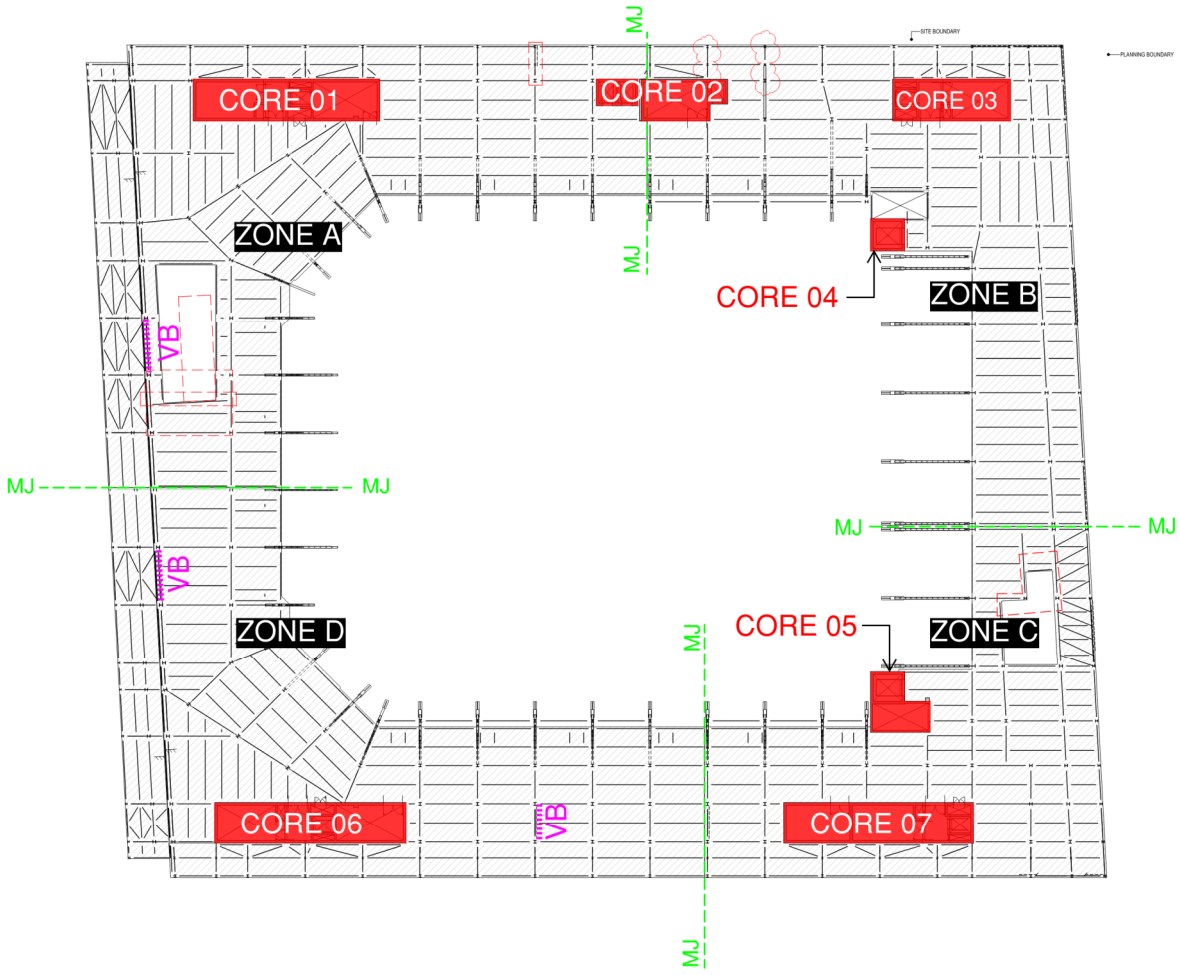


Figure 4—1 Movement joints and stability elements

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4.2 Stability load path

When the building is loaded, the load is transferred from the envelope via diaphragm action typically through the composite deck into the vertical stability cores and braced bays. In addition to these primary stability elements, the raker beams also contribute to the resistance of overturning forces by attracting lateral loads at the upper levels of the building and transferring them down to the lower levels where the floor plate is deeper and stiffer.

The static loadings resisted by the core and shear walls are:

- Vertical gravity loads from the roof supported on each core.
- Vertical gravity loads from adjacent floor structures.
- Lateral wind loading applied to both the roof and the bowl, in any direction.
- Crowd action on the terraces creating a horizontal load applied to the rakers.
- Imperfections resulting from construction tolerances in the constructed frame causing small notional horizontal loads in the structure.

The core and shear walls in each portion of the building (separated by the movement joints) must be strong enough to resist these static loadings and stiff enough to control the dynamic sway response of the stand.

4.3 Core Walls

RC stability walls are present in each zone as highlighted in Figure 4—1 and enclose vertical circulation stair and lift shafts. Each cluster of walls work together to form a core which acts as a vertical cantilever to resist lateral stability loadings and vertical gravity loads.

Perimeter walls are typically 400mm thick while internal walls are typically 300thick. It should be noted that there is a potential opportunity to reduce the wall thickness of many of the perimeter walls to 350mm thick. This should be considered in parallel with development of interfacing superstructure design as interface forces are substantial, particularly as a result of the building overhangs.

- Preliminary primary reinforcement intent sketches are included within Appendix A.
- Walls, where exposed and required by the architectural design, are to be fair faced and in most cases are expected to be exposed. Further information about required finish standards for concrete structures can be found in the Buro Happold concrete specification BRA-BHE-ZZ-ZZ-SP-S-0100.

Stairs and landings within cores are assumed to be of precast concrete, by the precast concrete subcontractor and are discussed in BRA-BHE-ZZ-ZZ-RP-S-0220. Note that the use of precast stairs and landings effectively results in the creation of large shaft openings within each core. This creates relatively long distances between effective return wall restraints to the external core wall (refer to Figure 4—2) and contributes to the adoption of the strut and tie steelwork arrangement that must be in place to resist the large lateral forces imparted by the cantilevered box structures (refer to 4.3.4). The use of e.g. in-situ landings would have the benefit of stiffening the external core walls and would aid their ability to resist forces imparted by the cantilevered box structure, potentially resulting in a simplification of the plan strut and tie system currently shown (ref 4.3.4.1).

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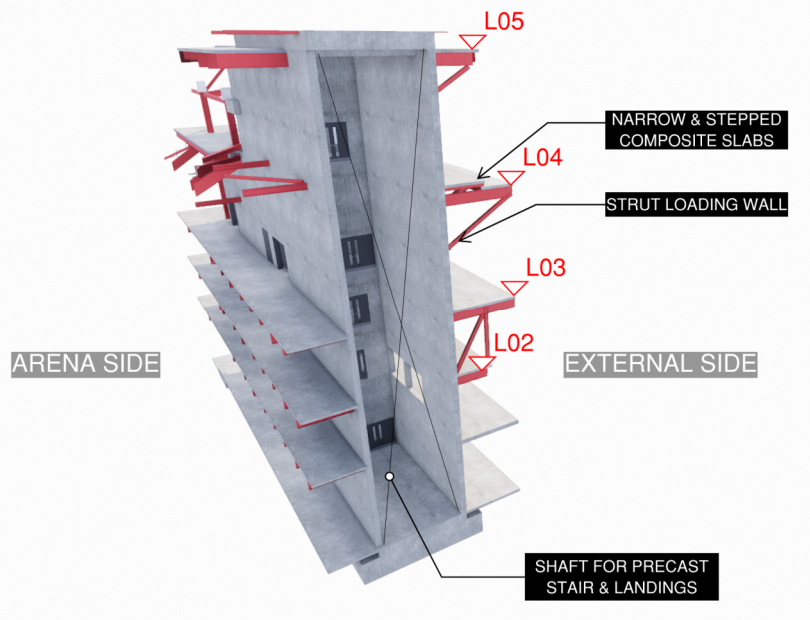


Figure 4—2 Large shaft for precast stair & landings

4.3.1 Wall Thickenings

Local wall thickenings are present at several typical locations as follows:

- Where roof support columns land at the head of the wall and increased cross-section is required to accommodate baseplate assemblies and higher local stresses.
- Where plan trusses connect into the side of the walls to accommodate anchorage assemblies

4.3.2 Wall Projections

Small cantilever wall projections are required at isolated locations to provide support to floor beams which sit eccentric to the core walls. The cantilevers are aligned with internal core walls as shown on typical example in Figure 4—3.

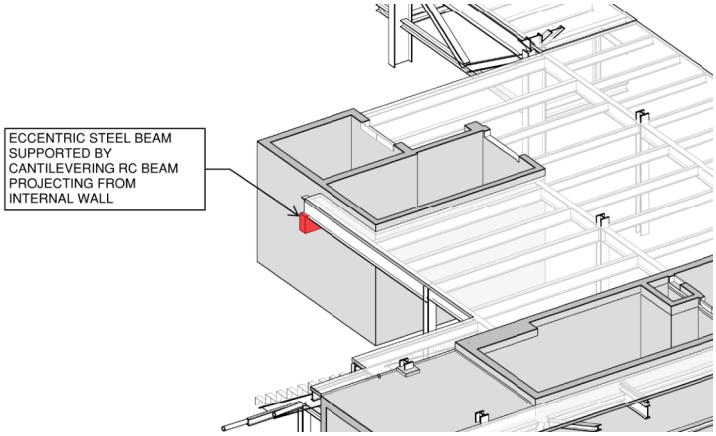
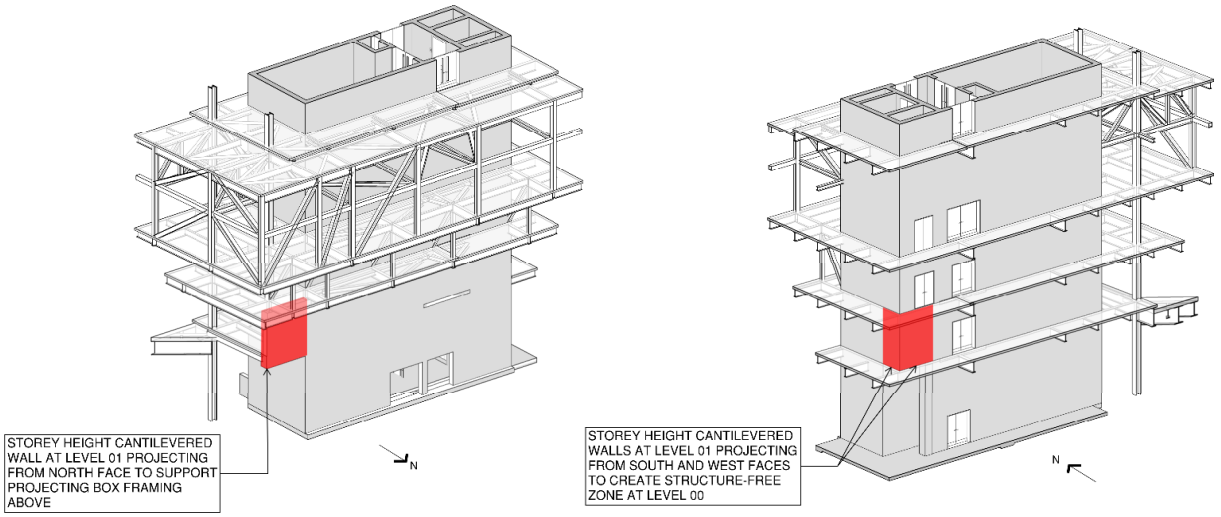


Figure 4—3 Support of eccentric floor beams

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Core 03 in Zone B contains a storey-height cantilevering projection from the north wall to the east to support cantilevered perimeter box corner framing. The cantilever bending reinforcement can be anchored into the stiff plane of the north wall.

Core 03 also contains an overhanging corner to the south west to create a structure free zone at Level 00. The west wall cantilevers to the south at each level to form the projection. This allows the south wall, which is penetrated by door openings nearby, to connect into the side of the west wall.



4.3.3 Floor beam connections

Steel plates are cast into RC walls with the outside face aligned to the external face of the wall to provide a clean interface to form a steel-to-steel, typically fin plate, connection with steel floor and raker beams. Arrays of shear studs and reinforcement are welded to the rear face of the cast-in plate to resist shear forces and axial loads respectively. A typical example of the principle is as shown in Figure 4—4.

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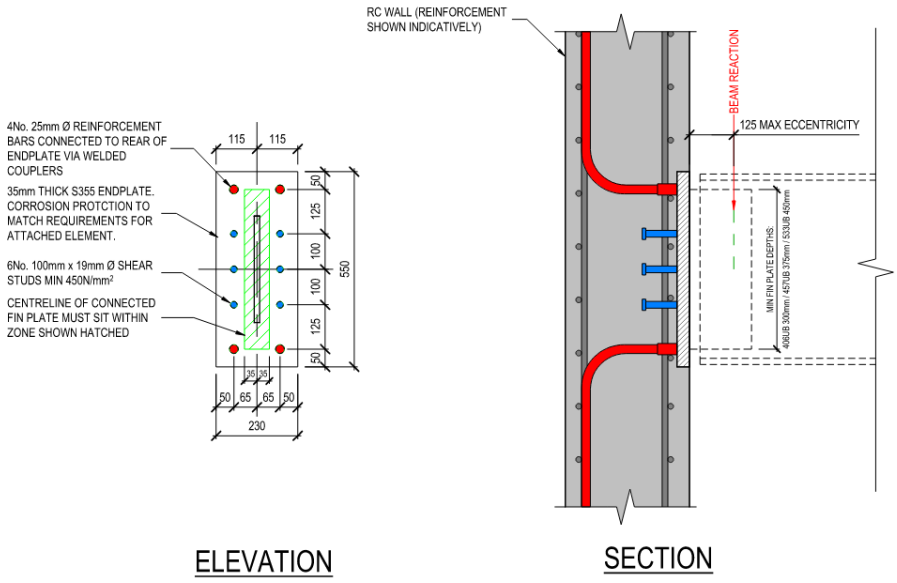


Figure 4—4 Typical floor beam cast-in plate connection

4.3.4 Cantilevered façade box support

The façade line of the building projects out at Level 02 and above by varying distances with the stepped profile offering no opportunity for direct support to the underside. Support to these projecting boxes must therefore cantilever out on each structural grid including at core locations in all zones (refer to Figure 4—5 for typical cross-section).

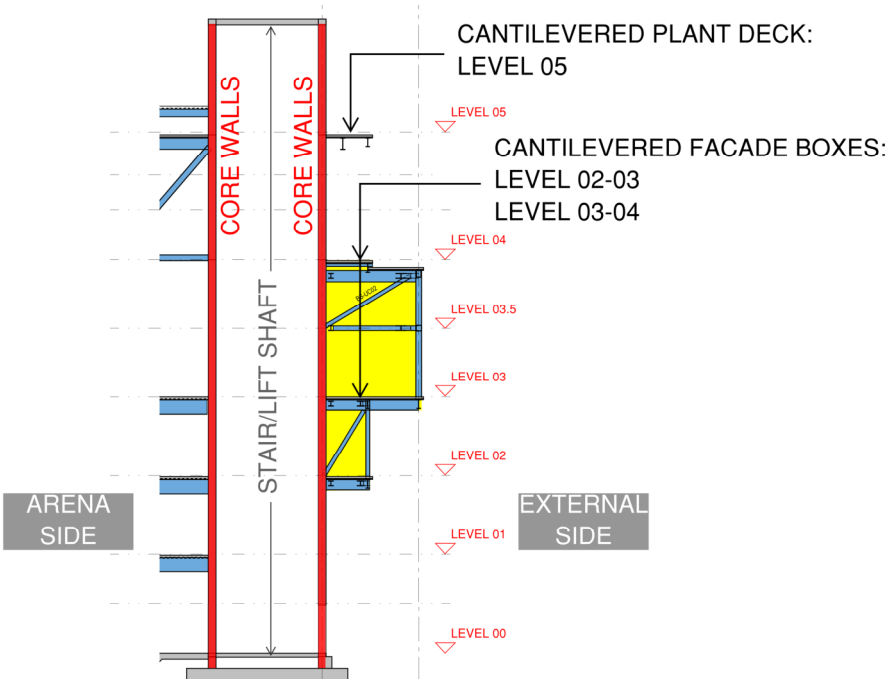


Figure 4—5 Typical cross section through core highlighting cantilevered massings to external face

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The weight of the lower and upper boxes is supported by raking steel struts on each structural grid at Levels 02-03 and Levels 03.5-04 respectively (refer to Figure 4—6). The lateral component of the strut force is large, and the magnitude is dependent on the raking angle which varies at each level dependent on spatial constraints. The struts connect into the perimeter core walls *away* from restraining return walls and therefore the loaded walls must span significant distances horizontally to transfer the load resulting in very large bending moments being generated. Note that the stairs and landings are of precast construction no restraint is provided by internal landing slab construction which, coupled with only very shallow slabs provided on the external face of the core, means that the wall is effectively forced to span horizontally.

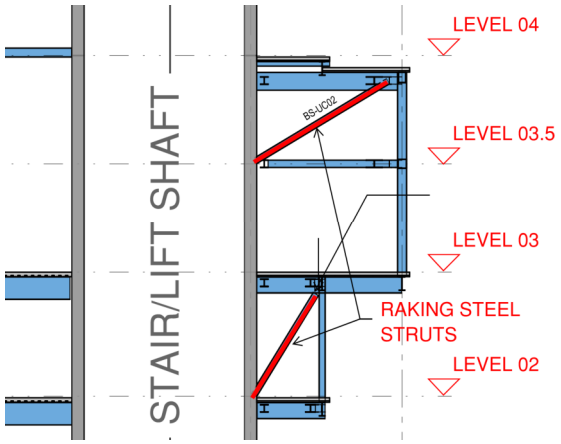


Figure 4—6 Struts

There is insufficient capacity within the wall to resist these bending moments and forces without the presence of significant thickenings. Therefore the proposal is to carry the lateral loads *directly* back to return core walls via struts and ties on plan at high and low level (refer to Figure 4—7 and Figure 4—9). A horizontally sliding connection must be provided at the vertical strut connection to the wall to ensure the lateral load is carried by this system rather than the wall (ref Figure 4—8) with similar principle at high level.

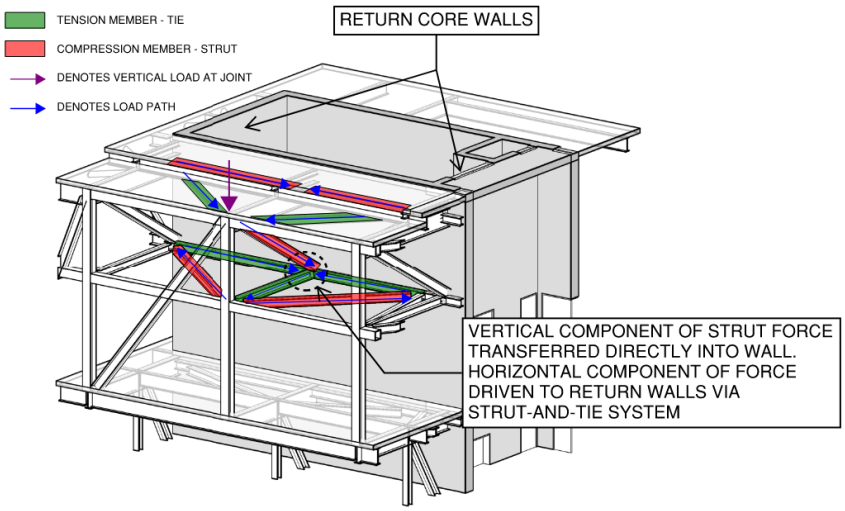


Figure 4—7 Strut and ties provided on plan to take horizontal force back to return walls

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The vertical component of the strut force is transferred directly into the core wall within a pocket detail to ensure there is minimal eccentricity of the imparted force from the wall centreline (refer to Figure 4—8). In order to provide adequate bearing a localised corbel thickening is provided within the wall. An increased band of horizontal reinforcement is required to resist the relatively small lateral load couple that results from the vertical force eccentricity.

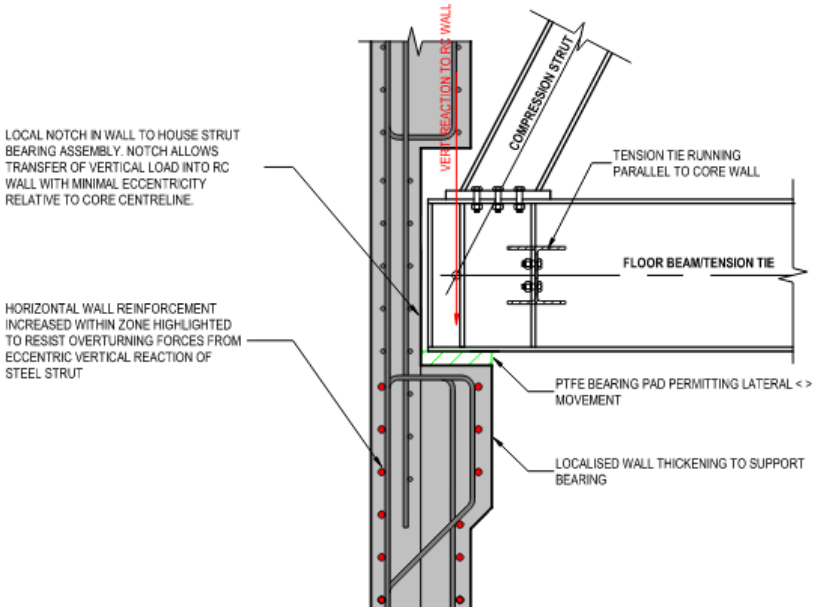


Figure 4—8 Typical strut bearing (section)

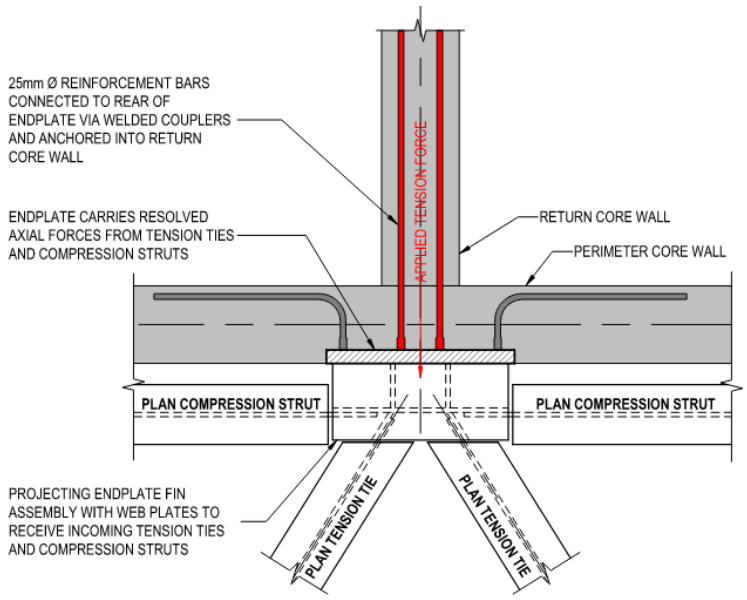


Figure 4—9 Plan strut and tie connection to return wall (plan view)

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4.3.4.1 Cantilevered Façade Box: Potential Alternative Options

The solution outlined in 4.3.4 requires a complex arrangement of steelwork and connections to resolve forces into the core walls at locations capable of resisting them. An alternative approach to the support of the cantilevered boxes could be explored as summarised below.

- Relocate cantilevered box support structure to align with core return walls:
    - Currently vertical support struts lie on the main structural grids to align with façade framing but away from core return walls. However, if struts were instead aligned with the core return walls lateral load would be imparted directly with no requirement for complex plan strut/ties and sliding connections. This approach has been adopted at Level 05 (refer to 4.3.5) where limitation re façade framing is not present and results in a straightforward structural approach.

As the stairs and landings are assumed to be of precast construction no restraint is provided by internal landing slab construction which, coupled with only very shallow slabs provided on the external face of the core, means that the wall is effectively forced to span horizontally resulting in the structural arrangement outlined in 4.3.4. Adopting in-situ landing slabs would have the benefit of stiffening the core walls and reduce the local bending in the walls if receiving strut forces directly but this approach would need to develop to ascertain whether it could lead to the removal of the plan strut and tie systems in their entirety.

4.3.5 Level 05 Cantilever Support

The floorplate at Level 05 projects out from the face of the core (ref Figure 4—5). At this level the strut and tie cantilever structures can be aligned with return core walls to take resolved forces back into walls directly (ref Figure 4—10).

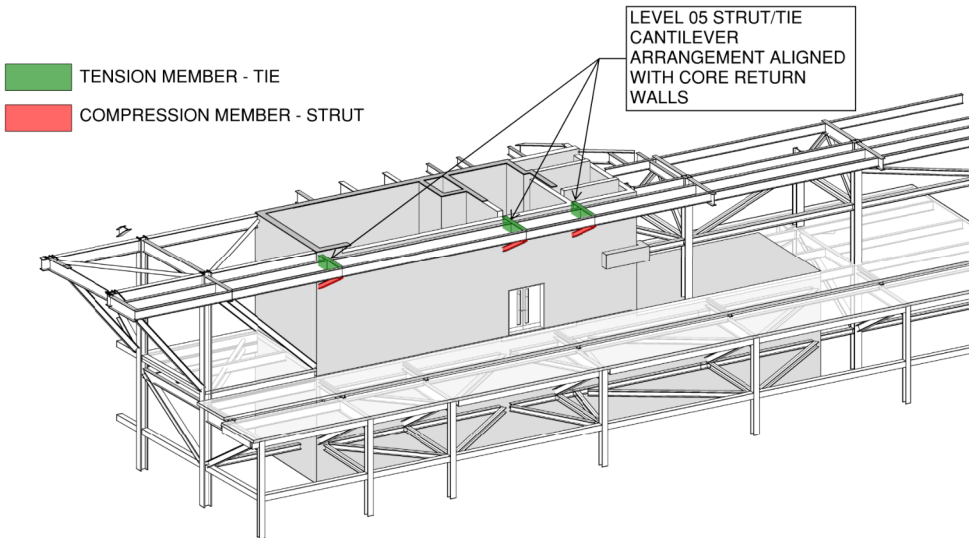


Figure 4—10 Level 05 cantilevers aligned with return core walls

4.4 Composite Metal Deck Slabs

Metal deck slabs are assumed to be part of the steelwork package (TBC Main Contractor) and are discussed within the Steel Description report, BRA-BHE-ZZ-ZZ-RP-S-0230.

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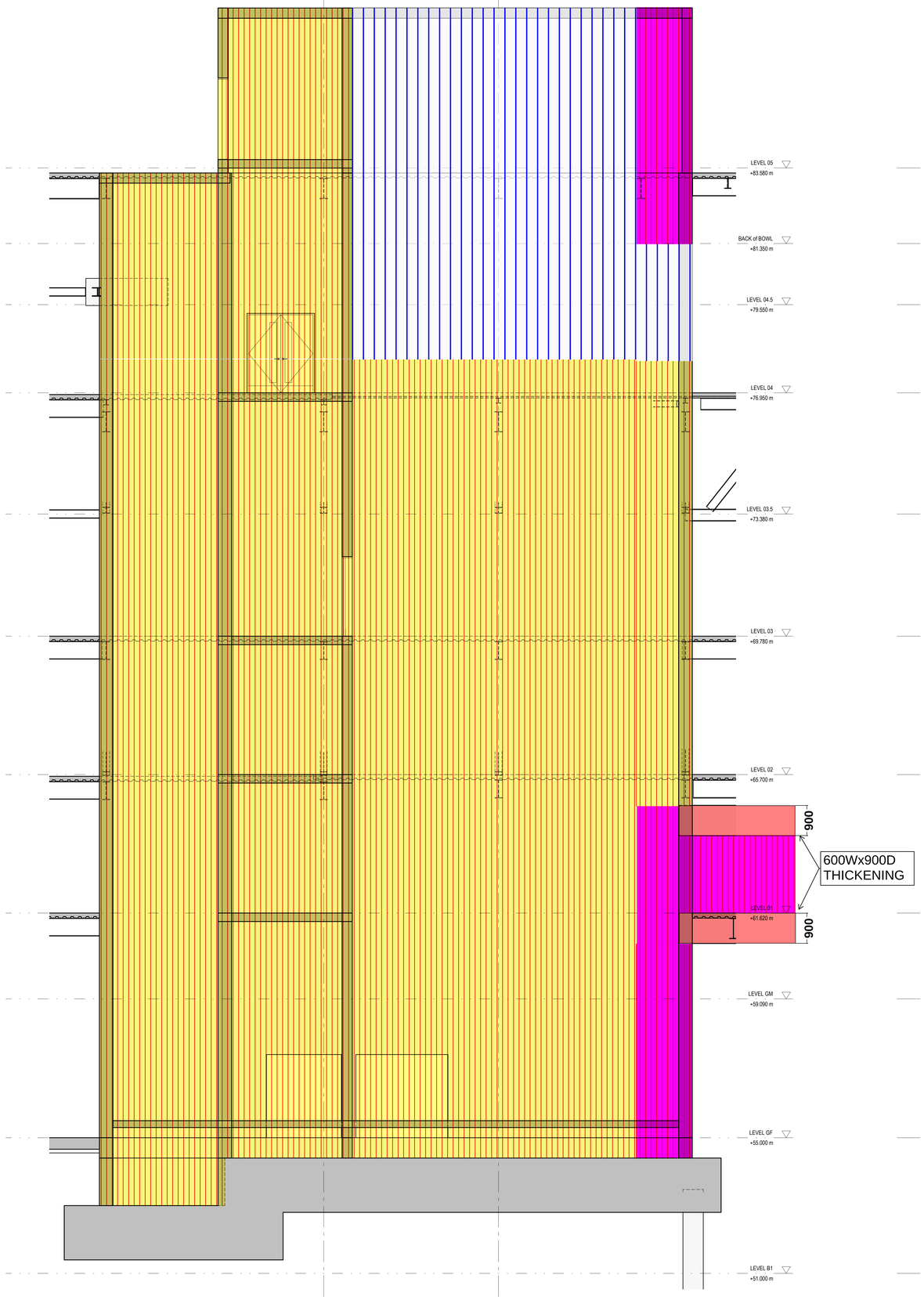
5 Health & Safety

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

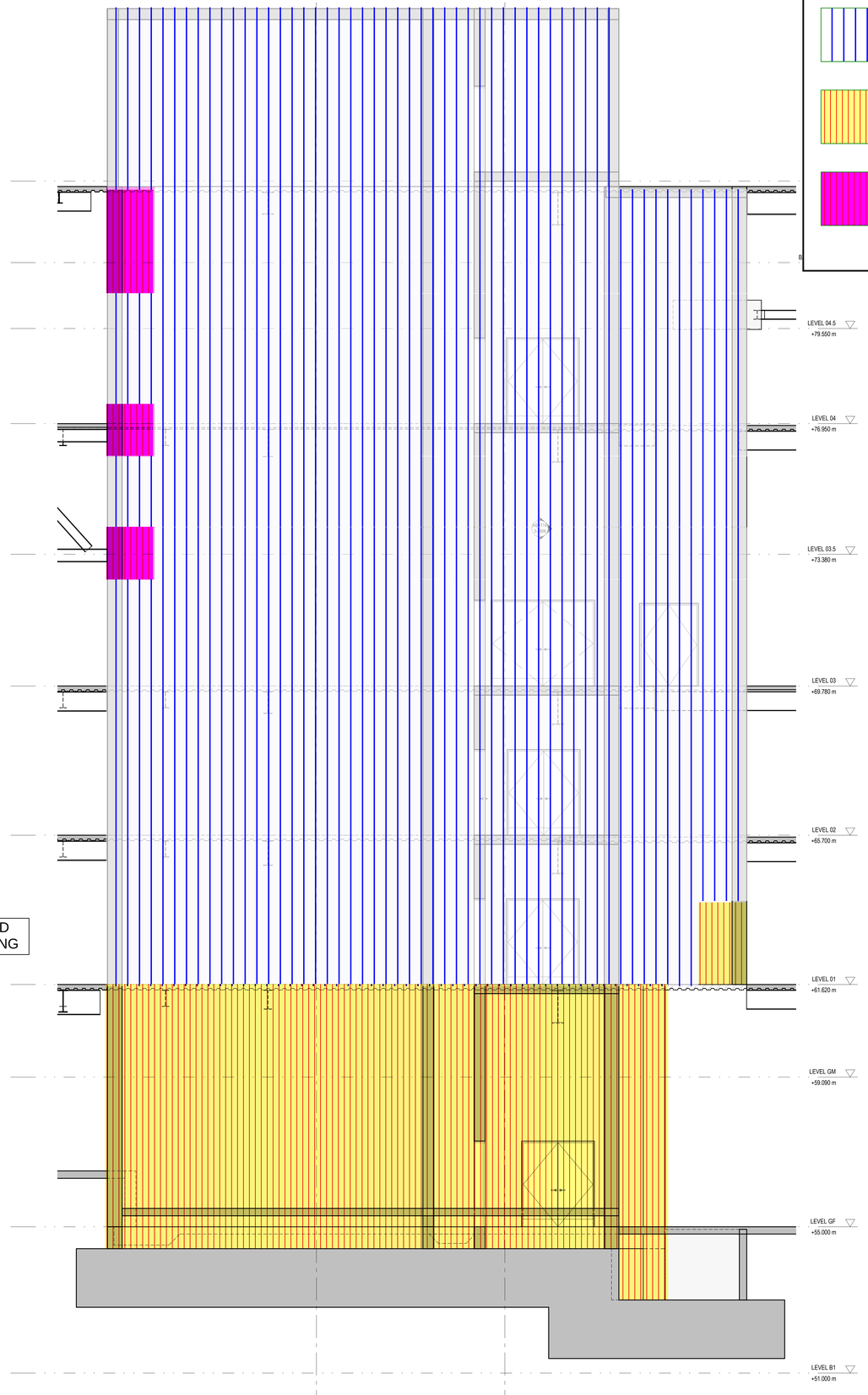
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Appendix A Core Reinforcement Intent Sketches

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1 DET. REF. S-4531 - CORE 03 ELEVATION WC03-A
SCALE 1 : 50



2 DET. REF. S-4531 - CORE 03 ELEVATION WC03-B
SCALE 1 : 50

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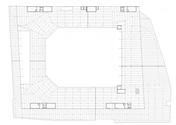
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VERTICAL H25-150 EF

MAINTENANCE/CLEANING/OPERATION

DECOMMISSIONING/DEMOLITION

Key Plan

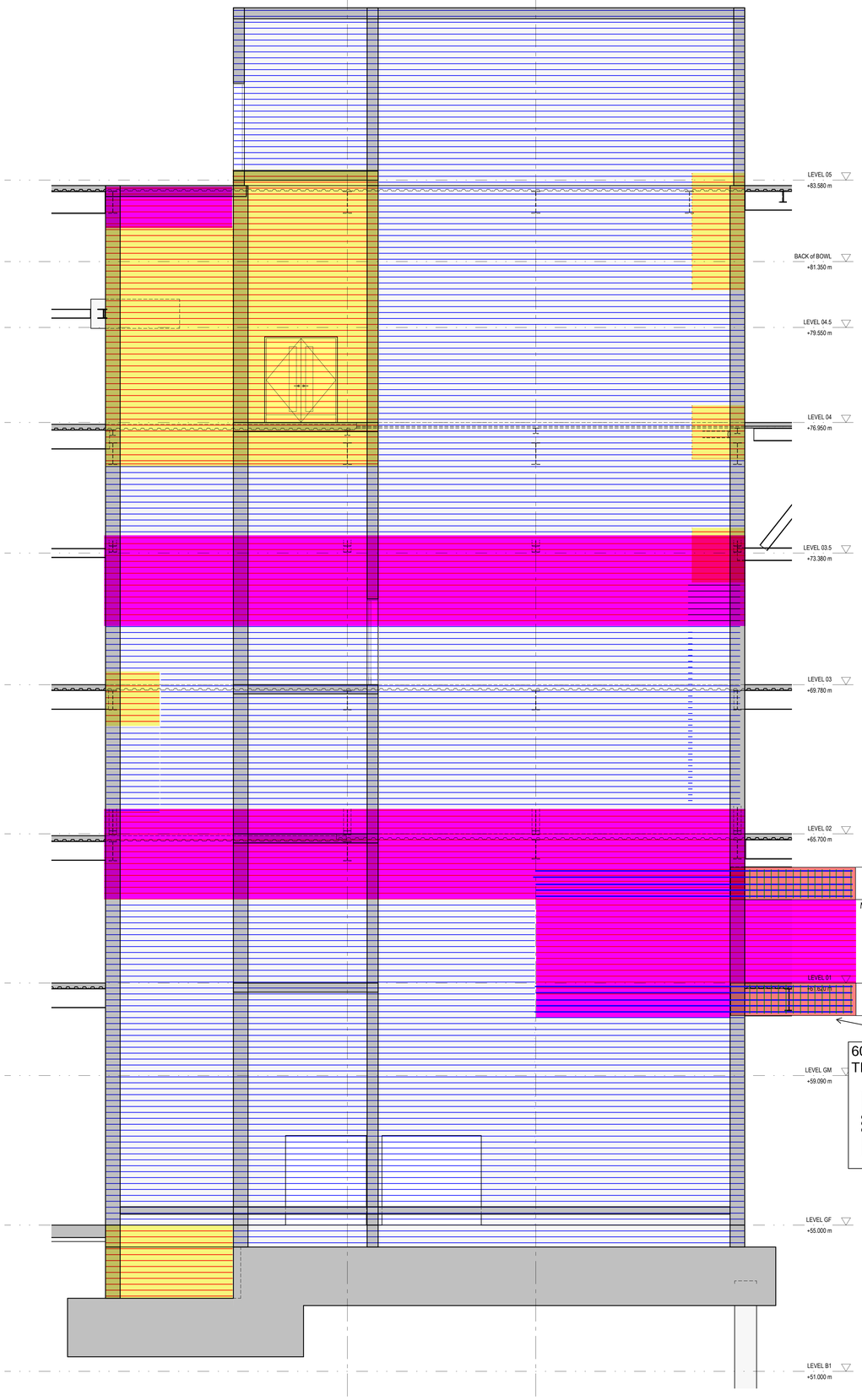


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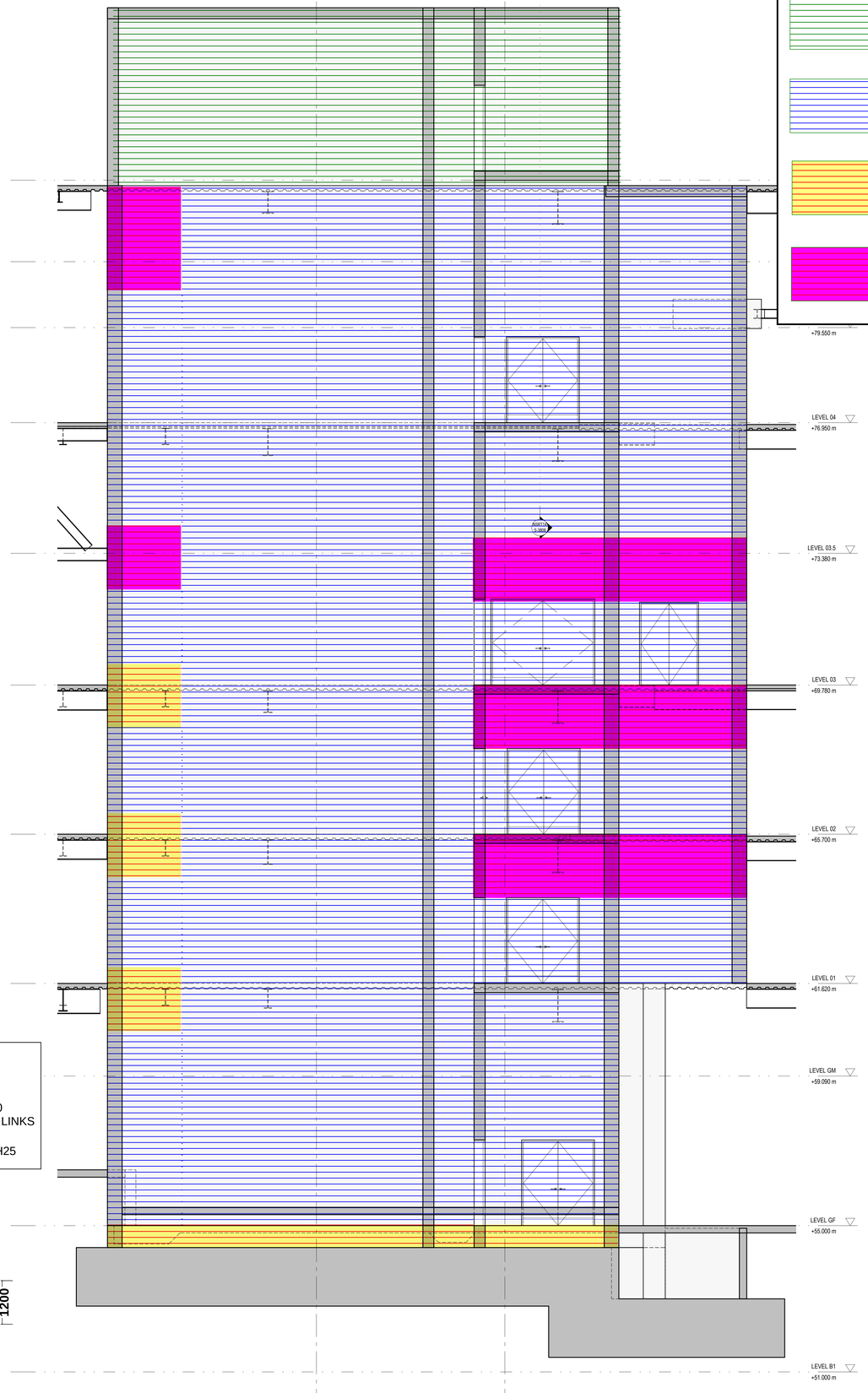
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STAGE 4A
ISSUED FOR TENDER / COSTING ONLY.

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APPENDIX A
CORE 03 PRELIMINARY REINFORCEMENT INTENT



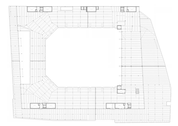
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Key Plan

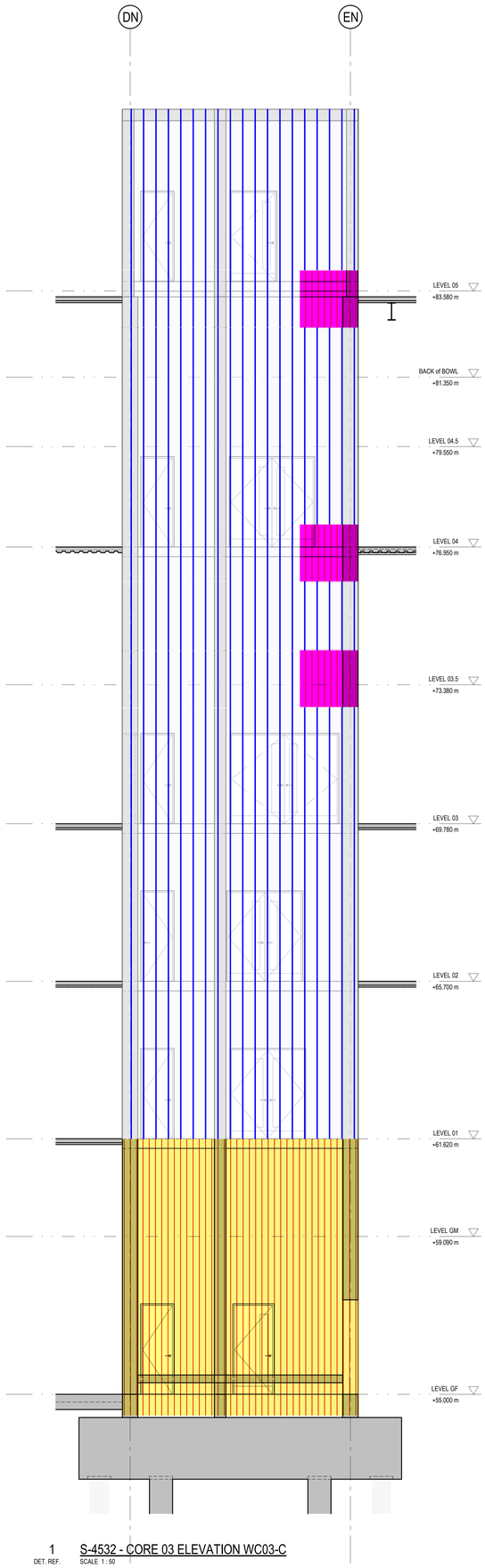


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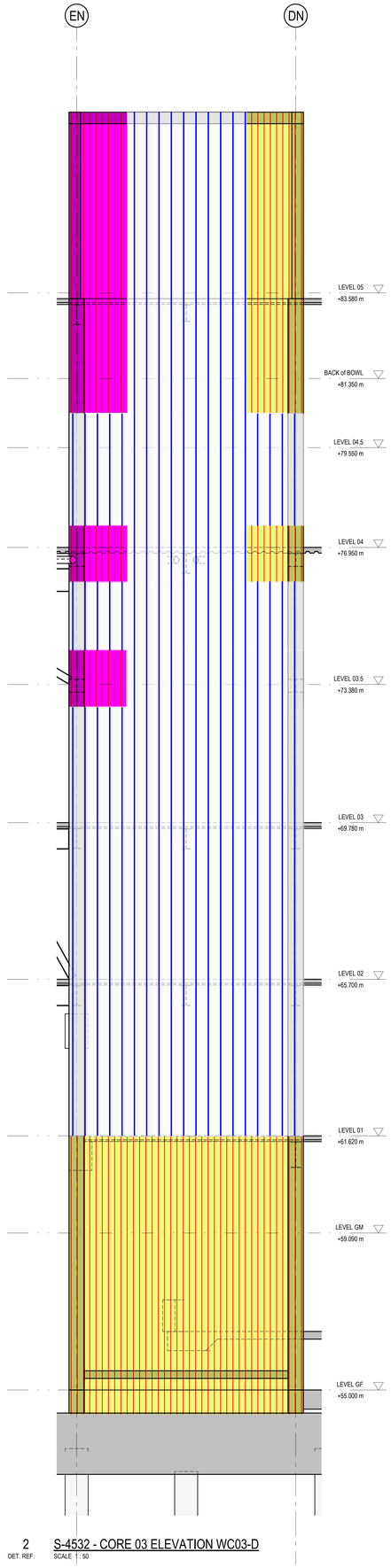
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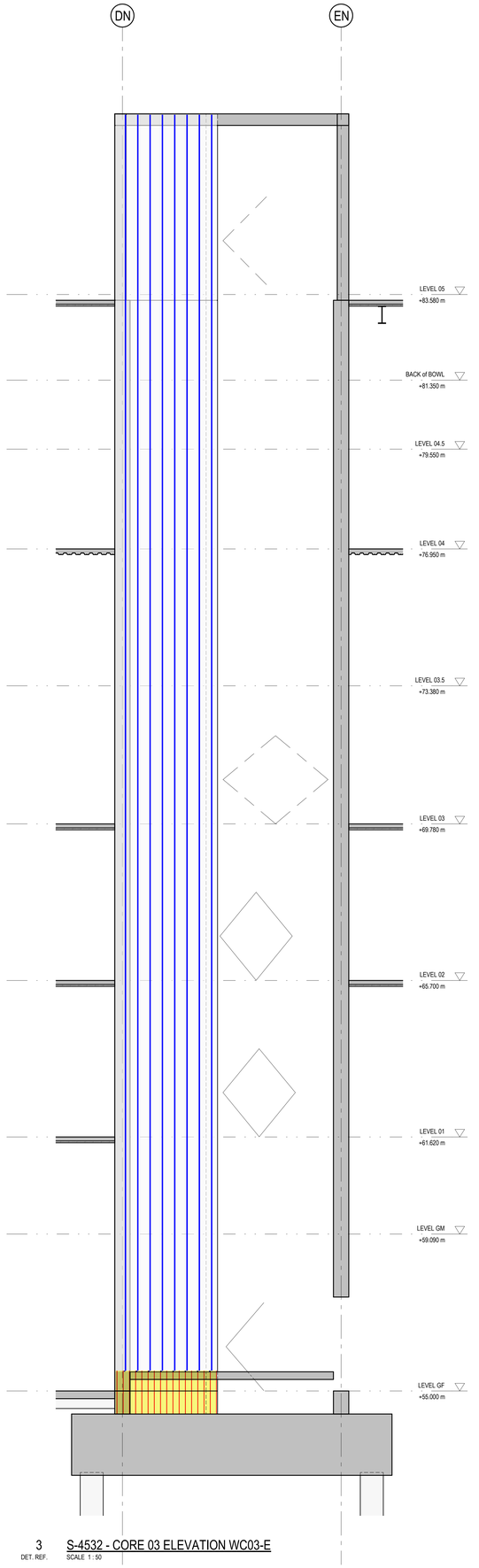
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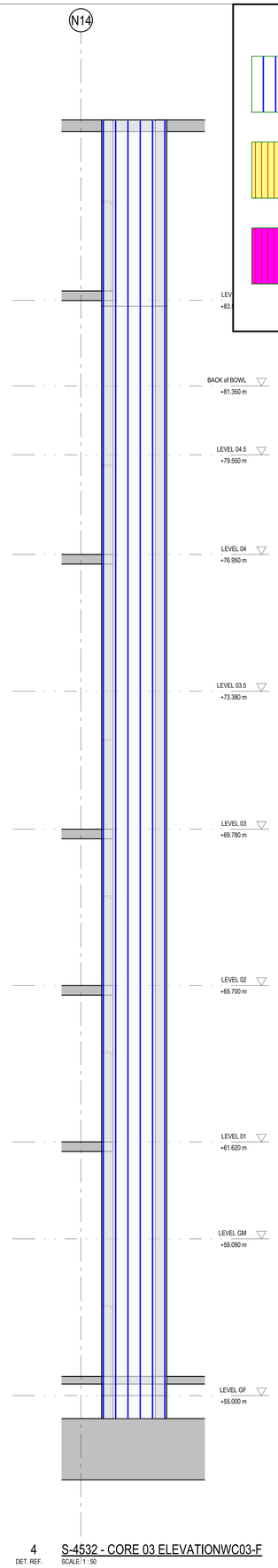
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3 DET. REF. S-4532 - CORE 03 ELEVATION WC03-E SCALE 1 : 50



4 DET. REF. S-4532 - CORE 03 ELEVATIONWC03-F SCALE 1 : 50

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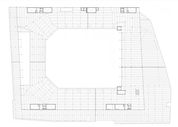
VERTICAL H20-150 EF

VERTICAL H25-150 EF

MAINTENANCE/CLEANING/OPERATION

DECOMMISSIONING/DEMOLITION

Key Plan

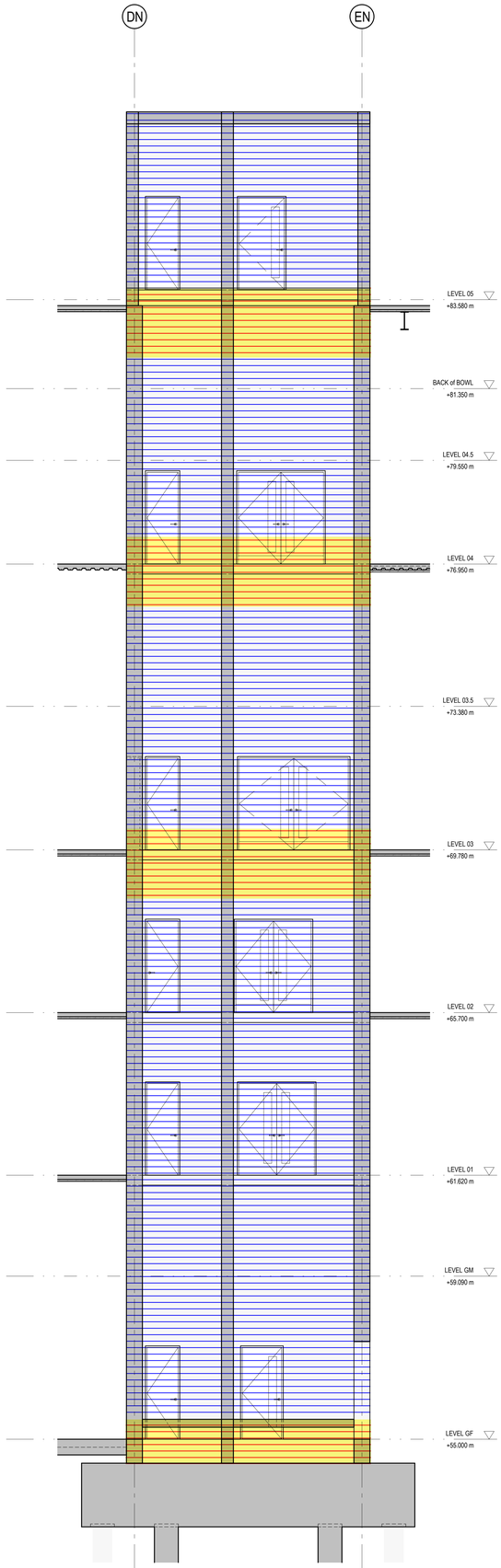


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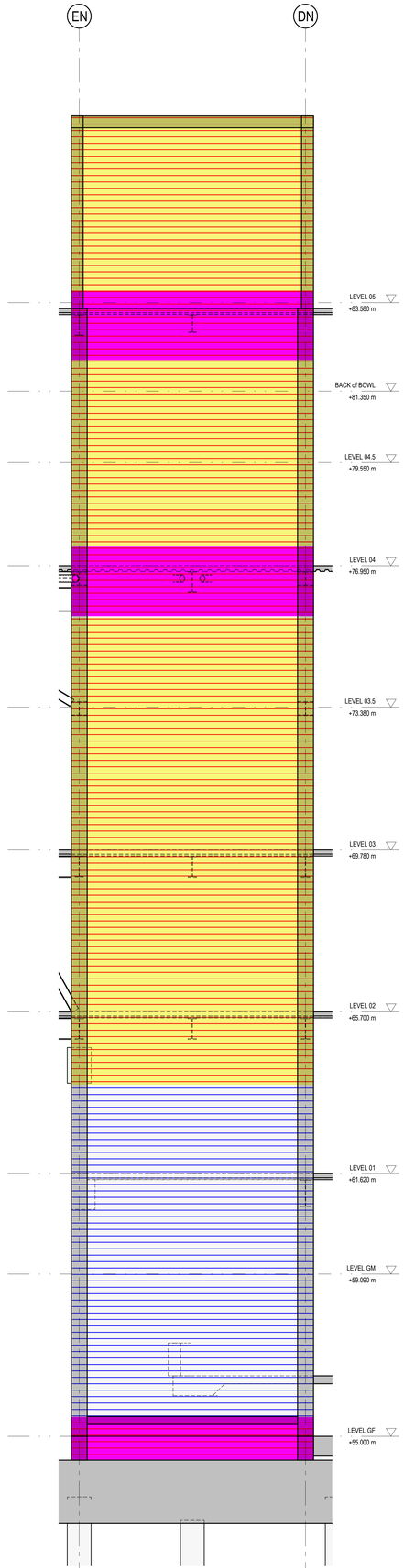
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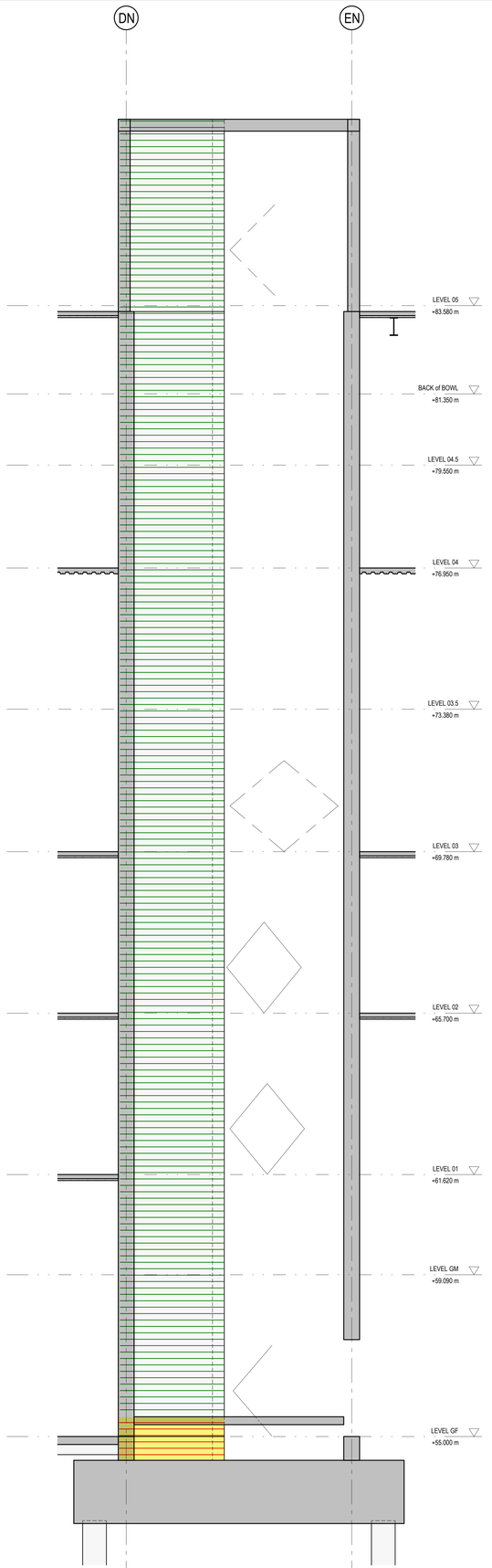
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CORE 03 PRELIMINARY REINFORCEMENT INTENT



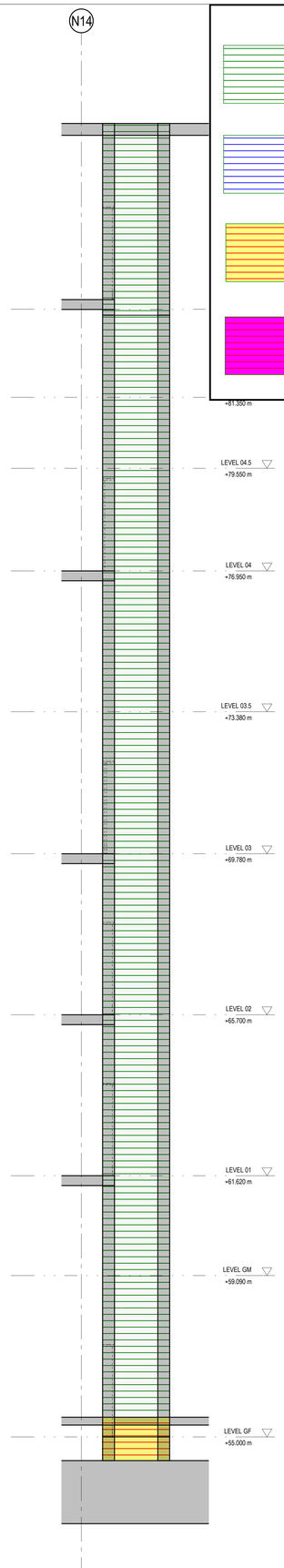
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3 DET. REF. S-4532 - CORE 03 ELEVATION WC03-E
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HORIZONTAL H12-150 EF

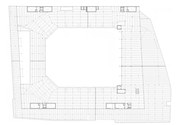
HORIZONTAL H16-150 EF

HORIZONTAL H20-150 EF

HORIZONTAL H25-150 EF

DECOMMISSIONING/DEMOLITION

Key Plan

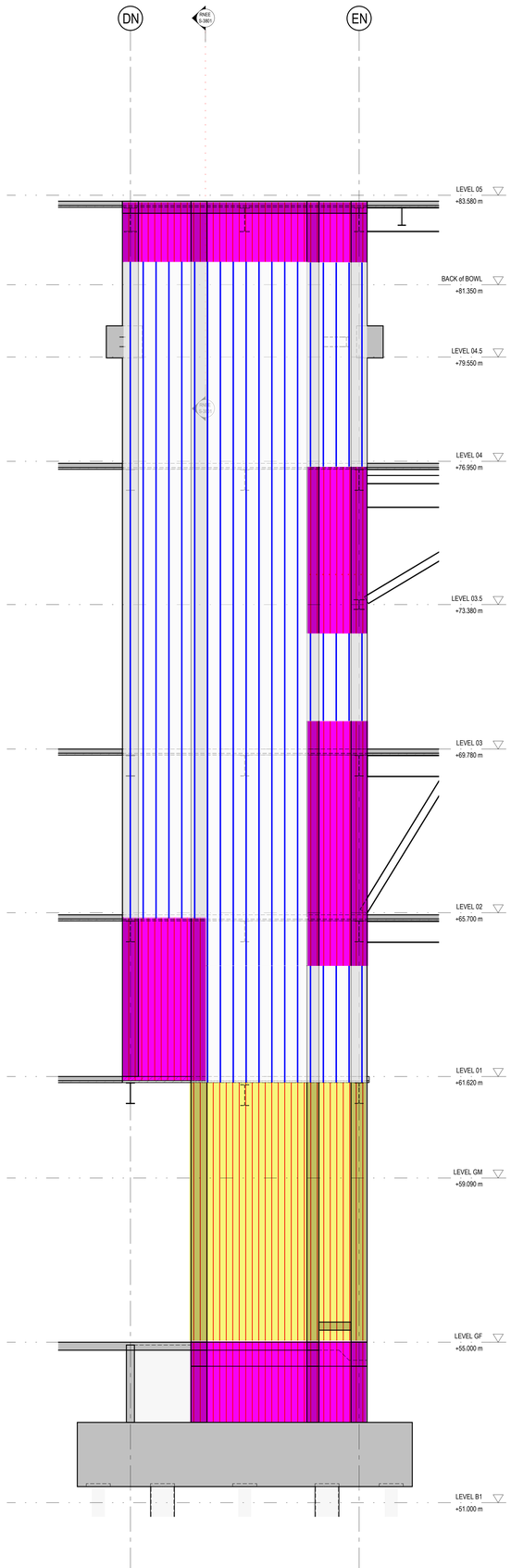


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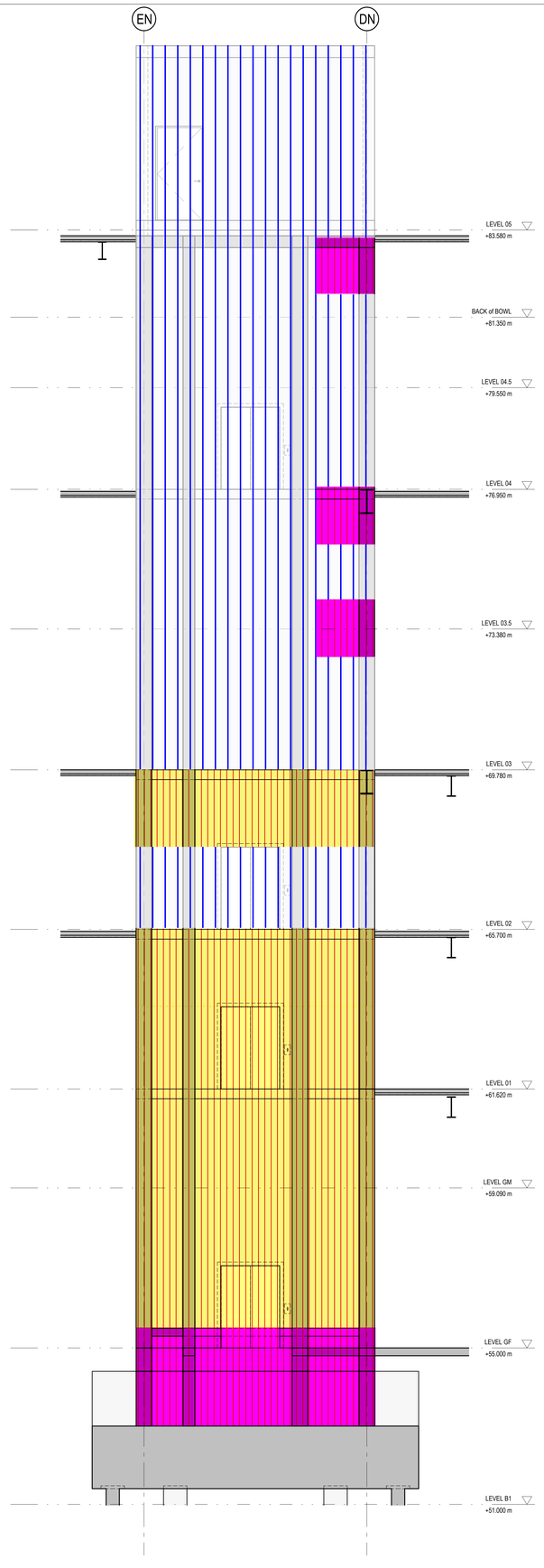
REFER TO S-4000 SERIES DRAWINGS FOR CORE GA PLANS AND S-4500 SERIES FOR CORE ELEVATIONS

STAGE 4A
ISSUED FOR TENDER / COSTING ONLY.

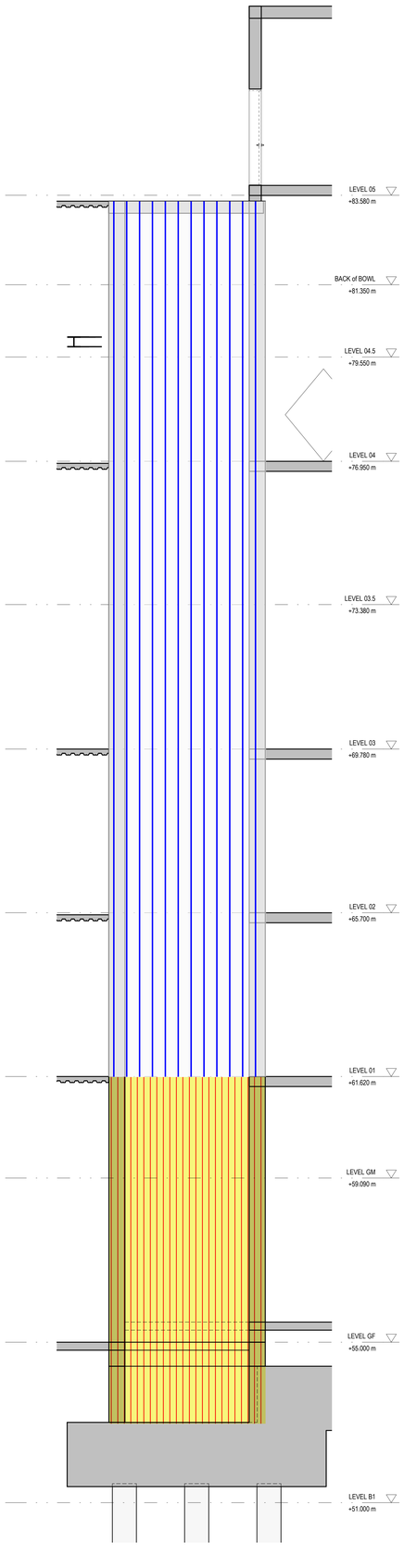
BRA-BHE-ZZ-XX-RP-S-0210
APPENDIX A
CORE 03 PRELIMINARY REINFORCEMENT INTENT



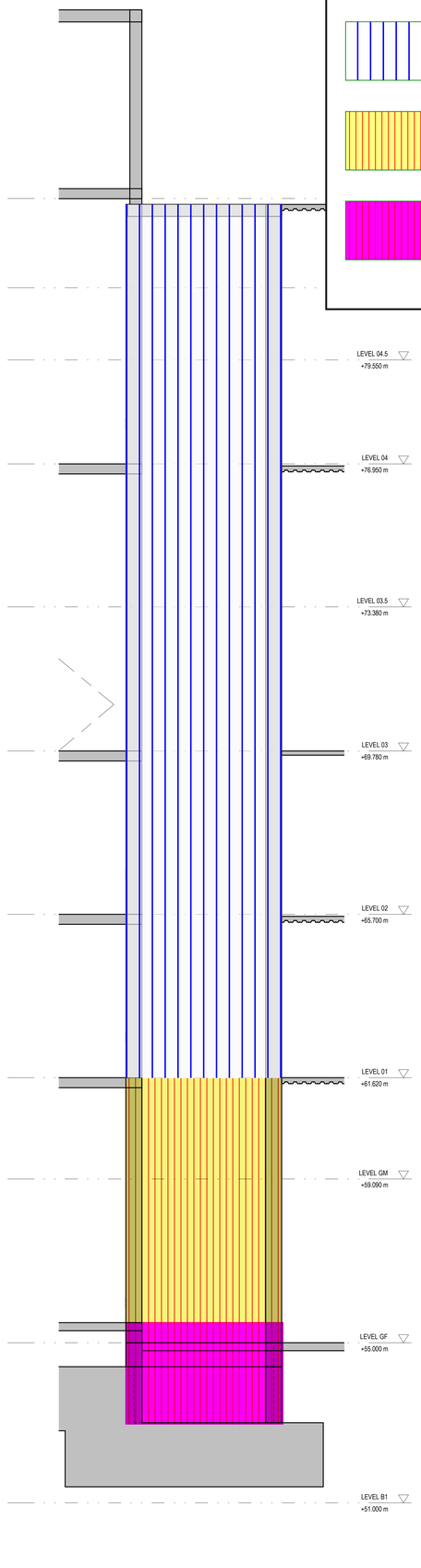
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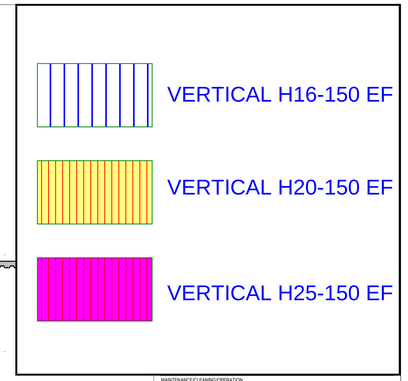
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3 DET. REF. S-4533 - CORE 03 ELEVATION WC03-J
SCALE 1 : 50



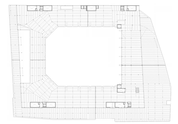
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MAINTENANCE/CLEANING/OPERATION

DECOMMISSIONING/DEMOLITION

Key Plan

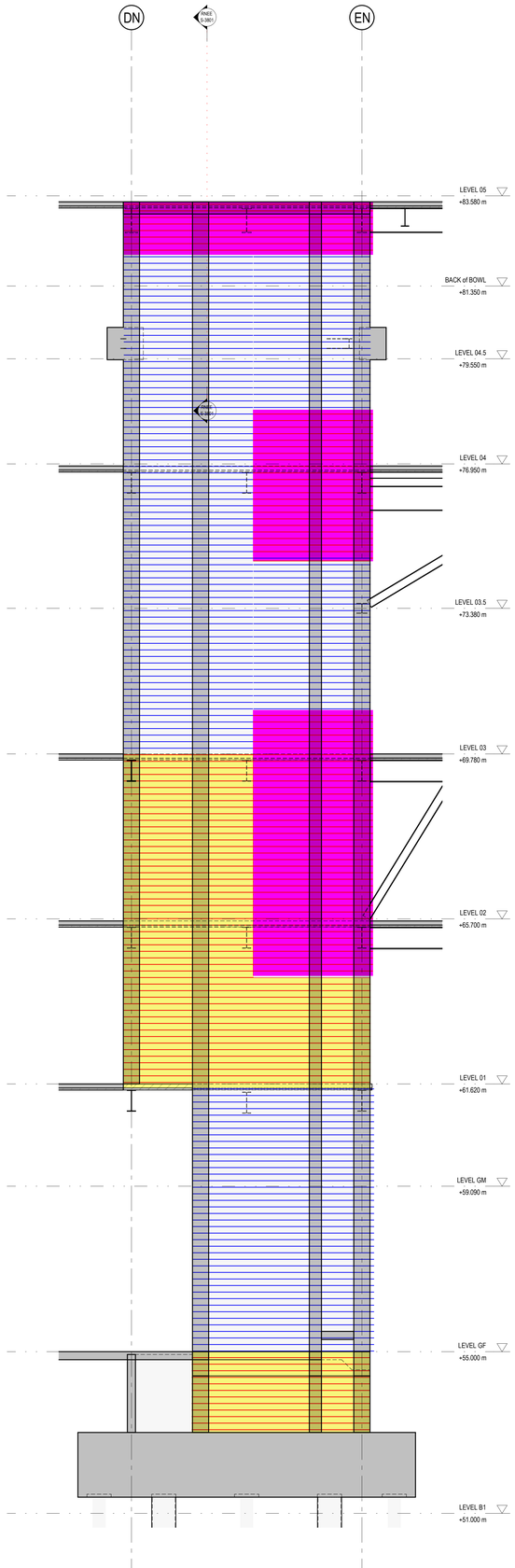


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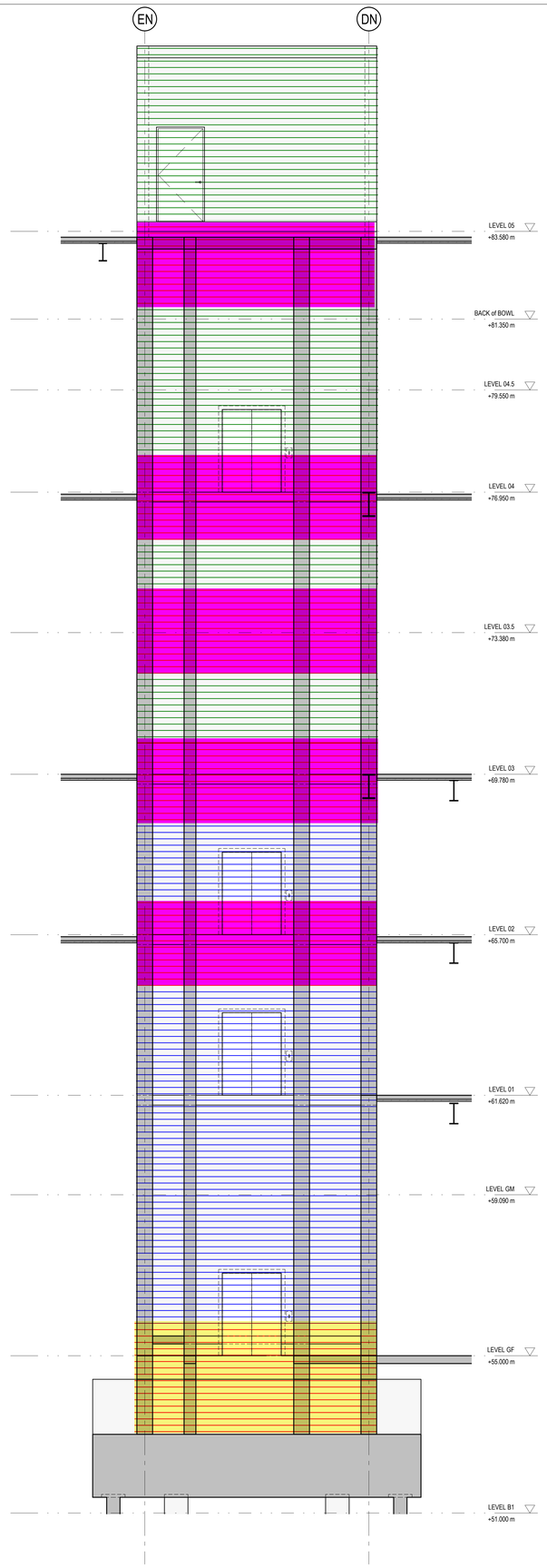
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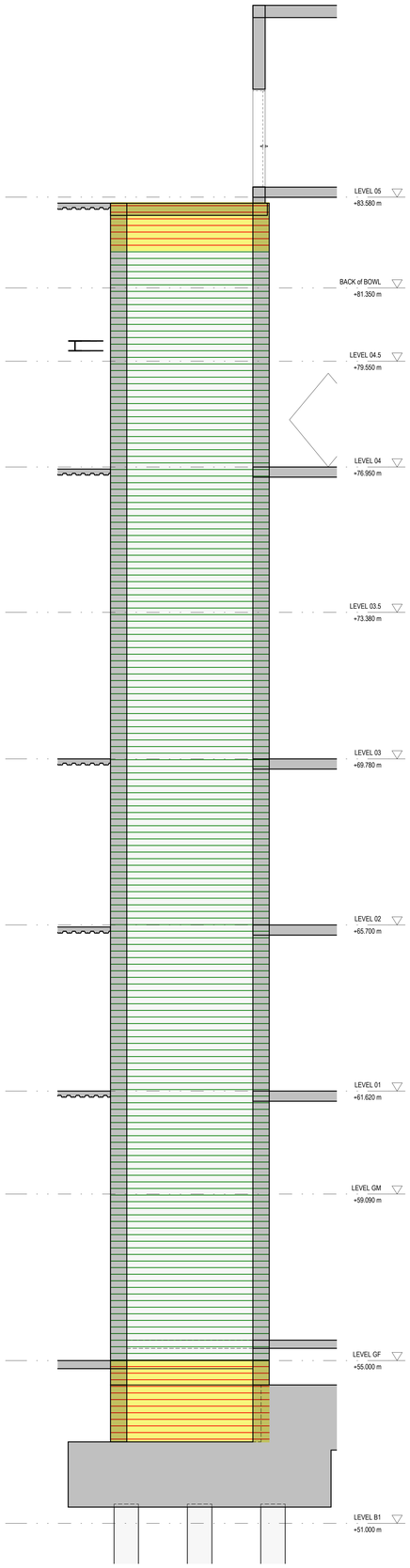
BRA-BHE-ZZ-XX-RP-S-0210
APPENDIX A
CORE 03 PRELIMINARY REINFORCEMENT INTENT



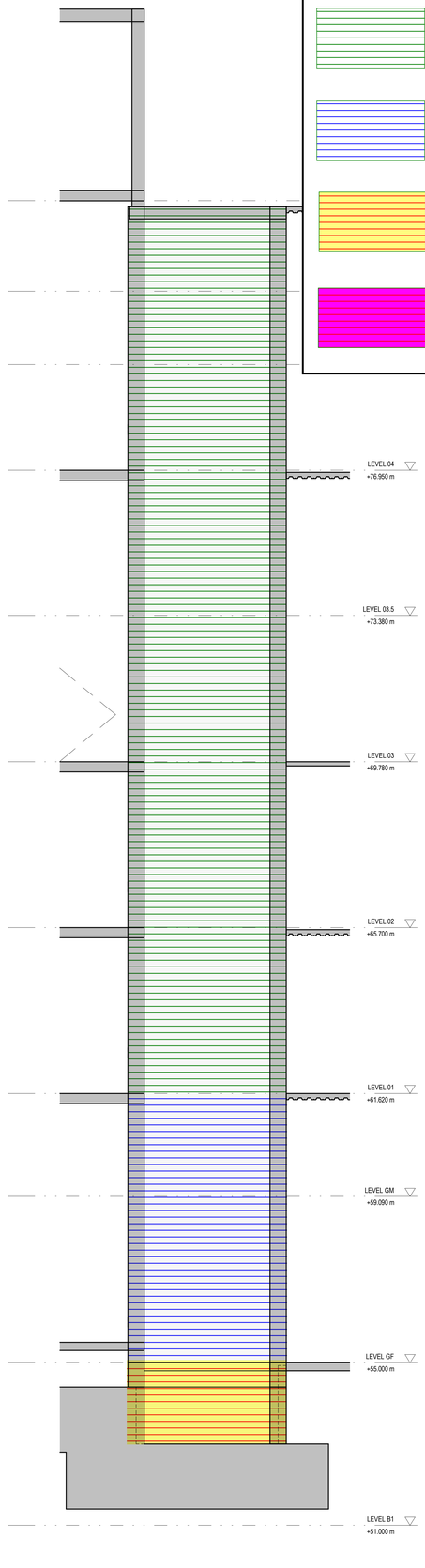
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2 DET. REF. S-4533 - CORE 03 ELEVATION WC03-H
SCALE 1 : 50



3 DET. REF. S-4533 - CORE 03 ELEVATION WC03-J
SCALE 1 : 50



4 DET. REF. S-4533 - CORE 03 ELEVATION WC03-K
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HORIZONTAL H12-150 EF

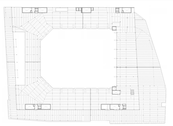
HORIZONTAL H16-150 EF

HORIZONTAL H20-150 EF

HORIZONTAL H25-150 EF

DECOMMISSIONING/DEMOLITION

Key Plan

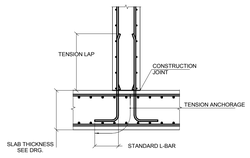


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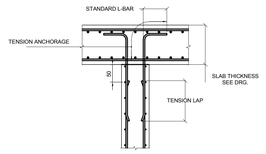
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STAGE 4A
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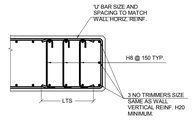
BRA-BHE-ZZ-XX-RP-S-0210
APPENDIX A
CORE 03 PRELIMINARY REINFORCEMENT INTENT



1 TYPICAL WALL STARTER BAR DETAIL
SCALE: NTS

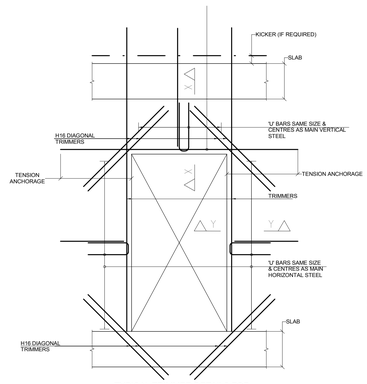


4 TYPICAL TOP OF WALL TERMINATION DETAIL (INTO SLAB)
SCALE: NTS

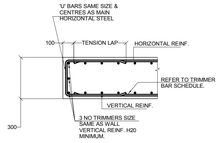


5 END SHEAR WALL PLAN DETAIL
SCALE: NTS

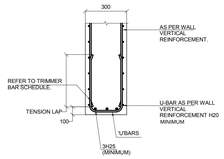
THIS DETAIL APPLIES TO SHEAR WALL WITHOUT BOUNDARY ELEMENTS. IF TIES WITH ONE 90 DEGREE LEG ARE USED, THOSE LEGS SHOULD BE LOCATED ON ALTERNATIVE FACES OF WALL.



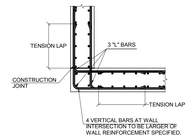
6 TYPICAL TRIMMER DETAILS FOR DOOR OPENINGS IN WALLS
SCALE: NTS



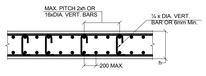
7 SECTION Y-Y
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8 SECTION X-X
SCALE: NTS

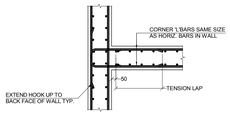


9 TYPICAL DETAIL AT BASE 90 DEGREE CORNER
SCALE: NTS

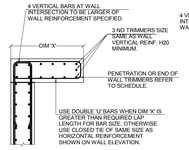


10 TYPICAL DETAIL OF HORIZONTAL RESTRAINING LINKS IN WALLS
SCALE: NTS

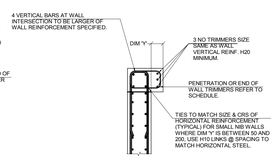
REQUIRED WHEN AREA OF VERTICAL REINFORCEMENT EXCEEDS 2% OF GROSS CROSS-SECTIONAL AREA OF SECTION. IF TIES WITH ONE 90 DEGREE LEG ARE USED, THOSE LEGS SHOULD BE LOCATED ON ALTERNATIVE FACES OF WALL.



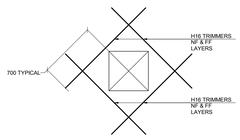
11 TYPICAL WALL HORIZONTAL TEE JUNCTION DETAIL



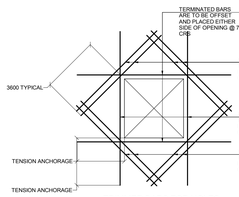
12 WALL CORNER DETAIL AT OPENING
SCALE: NTS



13 WALL CORNER DETAIL AT OPENING
SCALE: NTS



TRIMMER BARS FOR HOLES IN WALLS 200 TO 500 thk.
SCALE: NTS

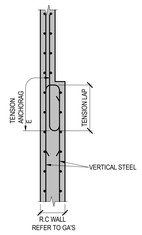


TRIMMER BARS FOR HOLES IN WALLS 500 TO 1000 thk.
SCALE: NTS
FOR TRIMMER BARS, REFER TO SCHEDULE.

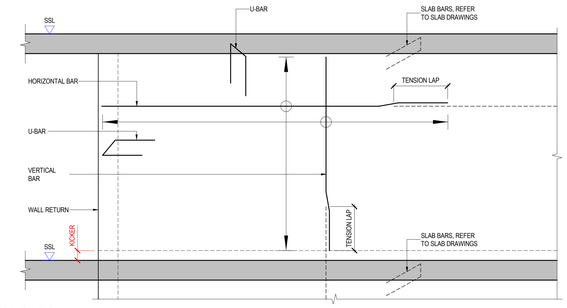
1. FOR HOLES WITH MAXIMUM DIMENSION UP TO 200mm, DISPLACE WALL REINFORCEMENT. NO U-BARS REQUIRED.
2. FOR HOLES >200 ≤ 500, SEE DETAIL 13.
3. FOR HOLES >500 ≤ 1000, SEE DETAIL 14.

MINIMUM TRIMMER BAR SCHEDULE FOR WALLS		
VERTICAL BARS IN WALLS	HORIZONTAL TRIMMERS E.F	VERTICAL TRIMMERS E.F
H12	2H16@75 CRS	2H20@75CRS
H16	2H16@75CRS	2H20@75CRS
H20	2H20@75CRS	2H20@75CRS
H25	2H20@75CRS	2H25@75CRS

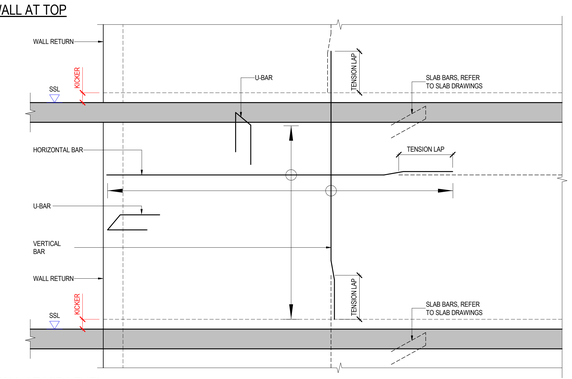
WHERE WALL REINFORCEMENT OCCURS AT EDGE OF PENETRATION, REDUCE MULTIPLE NUMBER OF TRIMMER BARS BY ONE NUMBER.



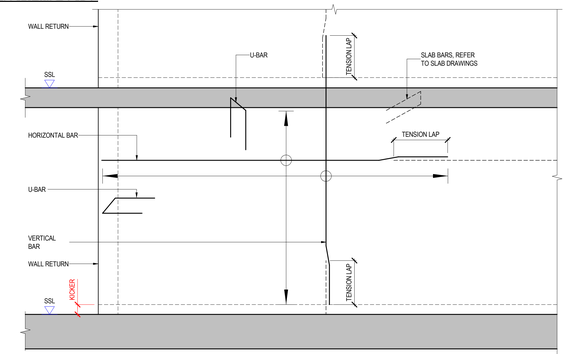
16 WALL THICKNESS CHANGE TYPICAL DETAIL
SCALE: NTS



R.C WALL AT TOP



R.C WALL AT MID LEVEL



R.C WALL AT FOUNDATION LEVEL

17 TYPICAL WALL REINFORCEMENT
SCALE: NTS

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SAFETY HEALTH AND ENVIRONMENTAL INFORMATION

IN ADDITION TO THE HAZARDS/RISKS NORMALLY ASSOCIATED WITH THE TYPES OF WORK DETAILED ON THIS DRAWING, NOTE THE FOLLOWING:

CONSTRUCTION:

MAINTENANCE/CLEANING/OPERATION:

DECOMMISSIONING/DEMOLITION:

Notes

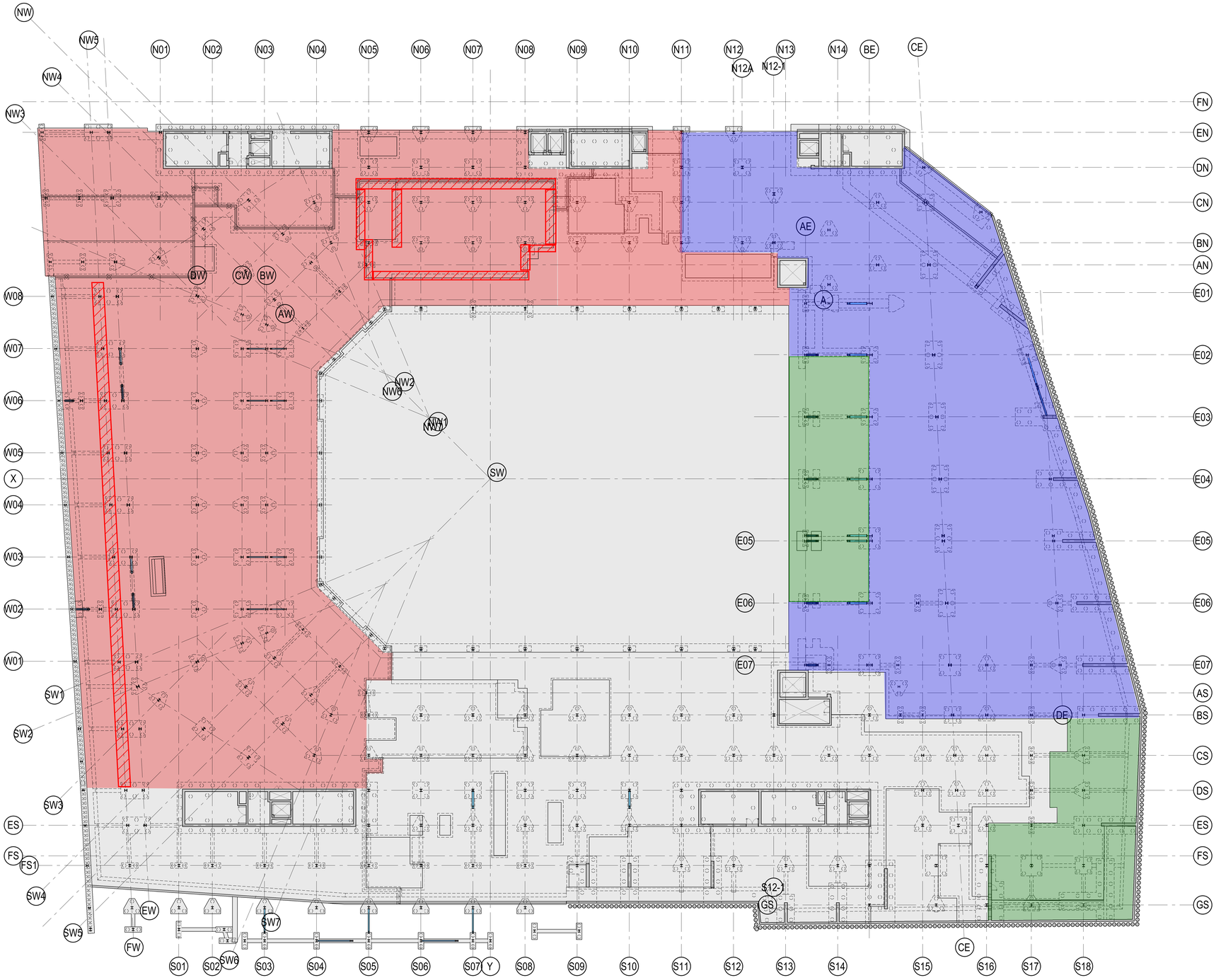
Rev	Description	Date	Drn	App'd

BRA-BHE-ZZ-XX-RP-S-0210
APPENDIX A
TYPICAL REINFORCEMENT DETAILS

Appendix B Ground Floor Reinforcement Allowances

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Additional Reinforcement Allowances



The reinforcement on the plan is in addition to the reinforcement requirements outlined in the Structural Description - In-situ Concrete Report BRA-BHE-ZZ-XX-RP-S-0210

- 200mm slab: Additional 35kg/m3
- 200mm slab: Additional 50kg/m3
- 300mm slab: Additional 35kg/m3
- 300mm slab: Additional 35kg/m3

Does not include upstand walls or additional allowances for steps and edge thickenings.

BUROHAPPOLD ENGINEERING

STRUCTURES

Job Title:
Project Bradford

Job Number:
042841

Sketch Title/Number:
Additional Reinforcement Allowances

Date:	Initials:
02/07/20	SL

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Appendix C L00 Slab Design for Secondary Consolidation

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BURO HAPPOLD

Design Note

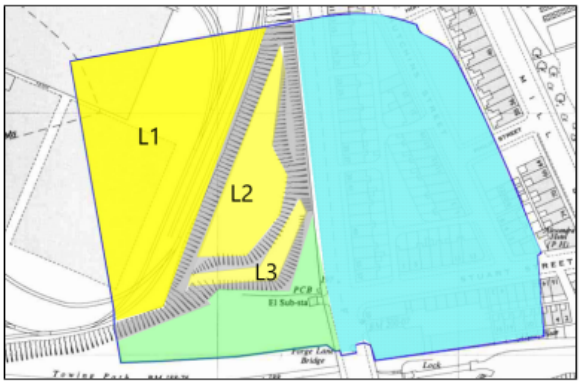
Project OVG Arena Manchester
Subject L00 Slab Design for Secondary Consolidation
Project no 042841
Date 3 July 2020

Revision	Description	Issued by	Date	Approved (signature)
P01	For Information	FS	09/06/20	Rob Amphlett
P02	For inclusion with Stage 4a Issue	FS	03/07/20	Rob Amphlett

1 Introduction

1.1 Background

This note provides a structural response to the previous Buro Happold geotechnical note on secondary consolidation of the made ground at the OVG arena site, to the west of Forge Lane. The previous note details how movements have been calculated based on values of consolidation coefficients, taken from applicable literature. These are summarised below.

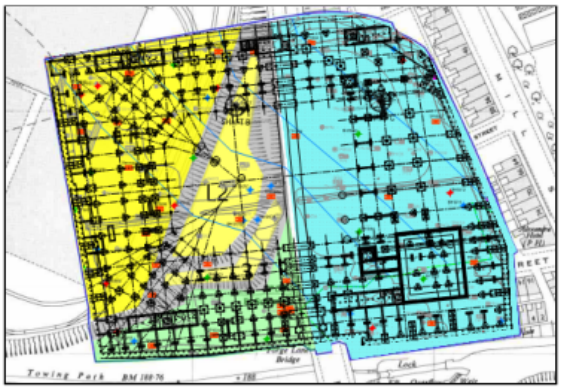


Secondary Consolidation Settlement (mm)

	min	median	max
L1	18	24	36
L2	11	14	21
L3	2	3	4

No settlement - floor slab excavation goes below the base of the fill

No settlement in this area - fill > 100yrs old



Settlement (mm)

	min	median	max
L1	18	24	36
L2	11	14	21
L3	2	3	4

No settlement - floor slab excavation goes below the base of the fill

No settlement in this area - fill > 100yrs old

These movements are expected to occur over the 50 year design life of the arena approximately linearly.

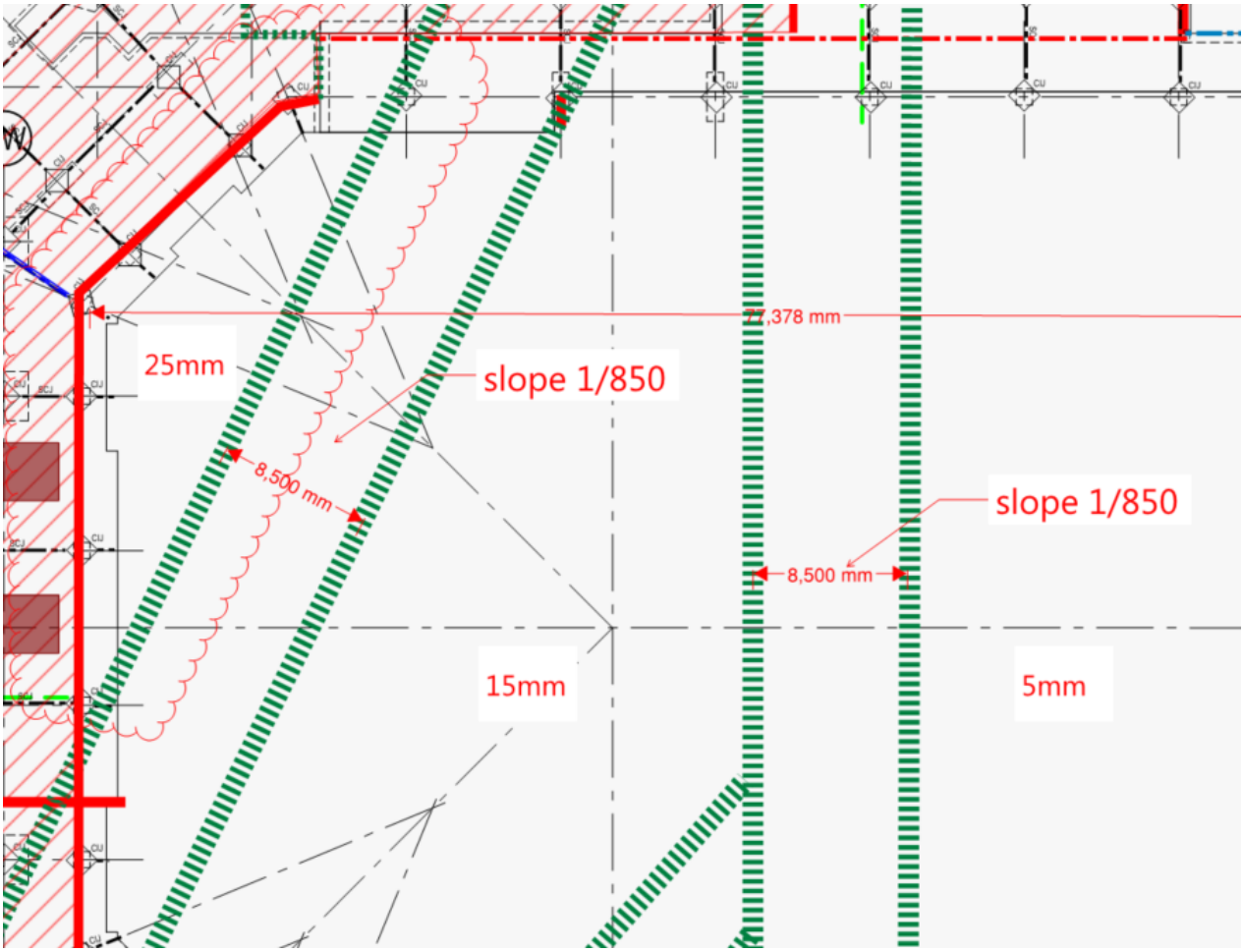
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It is recommended here that serviceability design of the structural slab is based on median values for ground movement. This is because there is likely to be significant local variation in ground movements, and worst case ground and structural movements are highly unlikely to be co-incident.

2 Event Floor

The event floor is formed from a 400thk RC ground bearing slab. It is tied into single pilecaps around the perimeter at the point of transition to the general 200thk slabs. As currently proposed, the interface is dowelled to control relative deflections and an edge thickening to the slab between the pilecaps will help control relative displacements between the pilecaps.

The buried embankment features cut through the western end of the event floor on a diagonal line, with differential settlement in the fill below likely to occur as a result. The median ground consolidation movements and approximate locations of buried features are shown below:

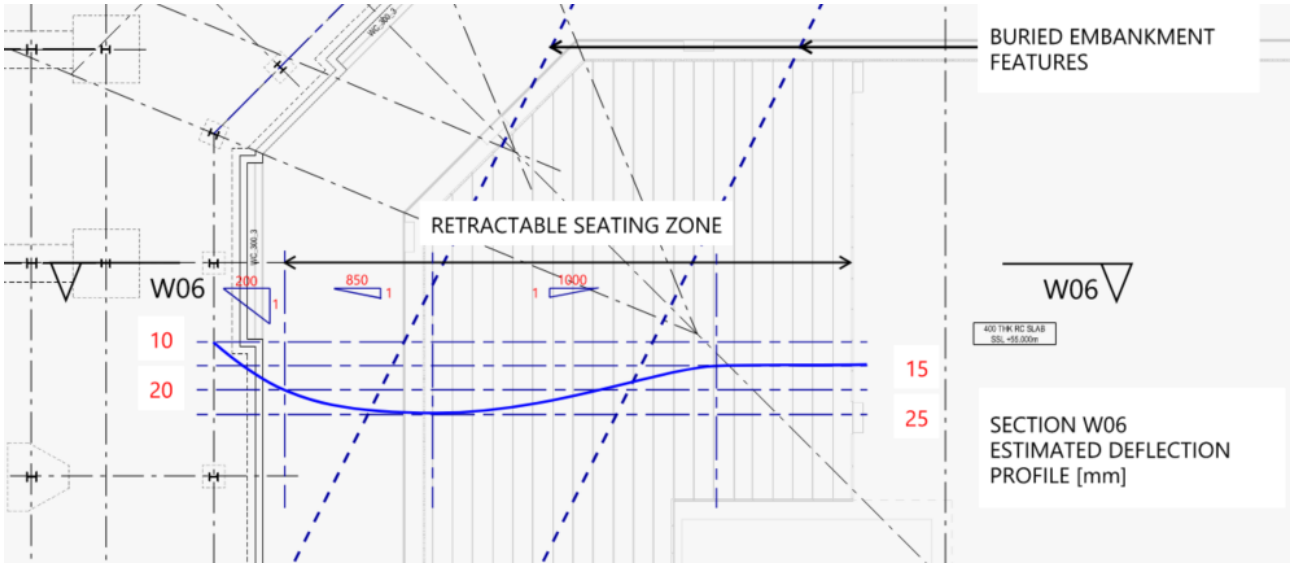


To enable the successful operation of the retractable seating on the event floor, the floor is to be produced to the highest practical standard of flatness and surface regularity. Audience Systems requirement for surface regularity is interpreted as SR1 (based on BS 8204-2 classifications), corresponding to 3mm deviation from a 2m straight edge. Additionally, all points on the floor should be cast within +/-15mm of the mean floor level. This is the condition of the slab at handover and is unlikely to be significantly affected by consolidation movements.

When considering the effect of the secondary consolidation on the usage of the slab, it is more appropriate to consider the FM (free movement) classes of TR34. Considering the height of the retractable units, a class of FM2 would likely be appropriate (forklifts operating between 8-13m high suitable for high-specification warehousing) as a residual condition.

The interpretation of FM2 is relevant because it deals with the effects of floor levelness on tall, slender equipment. The levelness criterion for FM2 is 6.5mm change in level within 3m, or an average slope of 1:460.

The likely settlement profile is shown in section below, considering a worst section on GL W06, with the greatest extent of slab exposed to the higher quantum of consolidation settlement.



Based on median consolidation movements, the gradient of the deflected shape of the slab under the first set of retractable seating would correspond to 1:850, which is better than the required 1:600 slope for the seating to operate successfully and would be further improved based on the flexural capacity of the slab to 1:1000 or 1:1250, further into the floor, under the subsequent seating units.

Outside the zone of retractable seating, a less onerous limit of 1:200-250 would be acceptable for a pedestrian walkway, based on typical building deflection limits.

It can be seen that, by inspection with a satisfactory maximum slope of 1:460, the secondary consolidation will produce a value of around half to a third of this movement, and therefore, based on its limited extent, it unlikely to lead to a loss of functionality for this local area of the floor. This is on the provision that the floor is cast and finished to within the SR1 requirements at handover.

3 Typical Slabs

Two types of movements are important for typical slabs, support settlement and slab deflection between supports. It is important to note that these creep movements are long term (c. 50 years) and should be based on long-term properties for the concrete material. In the long term, the concrete stiffness of the slab in flexure will be reduced to about 1/3 of its short term value.

Settlement of Supports

To determine the total movement of the slab, the settlement of the pilecaps will need to be considered. This is anticipated to be in the region of 5-15mm, with 10mm taken for long term considering some creep in the piles under compression. Note that this is the average superstructure movement after frame installation only, as the L00 slab is likely to follow in the construction sequence.

Movement of slabs between pilecaps

For typical slabs, movements are frequently compared to maximum slope criteria, depending on the load type. A span/360 deflection criterion is chosen for the movement in this case as applicable to all general areas of the structure.

Hence the total acceptable movement, for different grid sizes can be summarised as a combination of both movements. For structural bays larger than c.6m square, a consolidation movement of 25mm will be acceptable.

Grid [m]	Pilecap Settlement [mm]	Span/360 (Variable Loads) [mm]	Total Acceptable Movement [mm]	Median Consolidation [mm]
6.5	*10*	*18*	**28**	**25**
7	*10*	*19*	**29**	**25**
7.5	*10*	*21*	**31**	**25**
8	*10*	*22*	**32**	**25**
8.5	*10*	*24*	**34**	**25**
9	*10*	*25*	**35**	**25**

3.2 Reinforcement

The typical slabs are provided with A393 mesh reinforcement top and bottom, equating to 75kg/m^3 as an overall quantity. It is suggested that this be increased by 35kg/m^3 for the slab bays susceptible to secondary consolidation, to allow for their partial suspension. This additional provision will also account for necessary reinforcement to control cracking within the exposed, polished surface finish.

A further increase of 40kg/m^3 (i.e. to 150kg/m^3) is recommended in key locations, local to significant blockwork partitions. It is recommended that, to preserve top steel continuity, saw cut joints are not included in the slab top surface. Tied joints should still be provided at 30-40m centres as currently planned

3.2.1 Foundations

All pilecaps should be designed for enhanced loading from a 4m square of suspended slab, including SW, SDL and LL effects. This loading will be included within the final pile forces for contractor design and is anticipated to be within the Stage 3 design capacity, considering an average pile length of 25m.

A small number of additional settlement-reducing piles are recommended to limit deflections in key areas. These piles could be a smaller diameter (e.g. 450mm, if advantageous, based on piling contractor details design) and shorter than typical piles, socketed just within the rock stratum below the site.

4 Summary

It is recommended that the proposed L00 slab design can, with limited development, continue to meet the requirements of the overall design criteria, with respect to secondary consolidation movements of the fill beneath the site.

The key risks to be mitigated are differential slab movement leading to unacceptable cracking in the slab finish, and in partitions built off the slab.

The quantum of movement, and hence the acceptable differential movements have been calculated, and the slab capacity assessed for a typical condition. With additional reinforcement, it is believed that a 200thk slab will have sufficient capacity to account for a partly suspended design condition, if this occurs later in the life of the structure.

The key design changes are summarised below, and on the enclosed sketch mark-up.

- 10 additional 450dia single piles, circa 15m length, with 750x750x500 caps, 50kg/m^3 reinforcement
- 200 slab reinforcement increased from 75kg/m^3 to 110kg/m^3 for marked bays, with local enhancement to 150kg/m^3 in discrete areas under significantly long block walls
- Jointing approach to be rationalised to remove saw cut joints, with column isolation and tied contraction joint provision as per the existing design

5 Technical Appendix

Allowable Structural Movements

Grid [m]	Span/500 (Deflection sensitive elements, e.g. tall masonry walls) [mm]	Span/360 (Variable Loads) [mm]	Span/250 (Total loads) [mm]
6.5	13	18	26
7	14	19	28
7.5	15	21	30
8	16	22	32
8.5	17	24	34
9	18	25	36

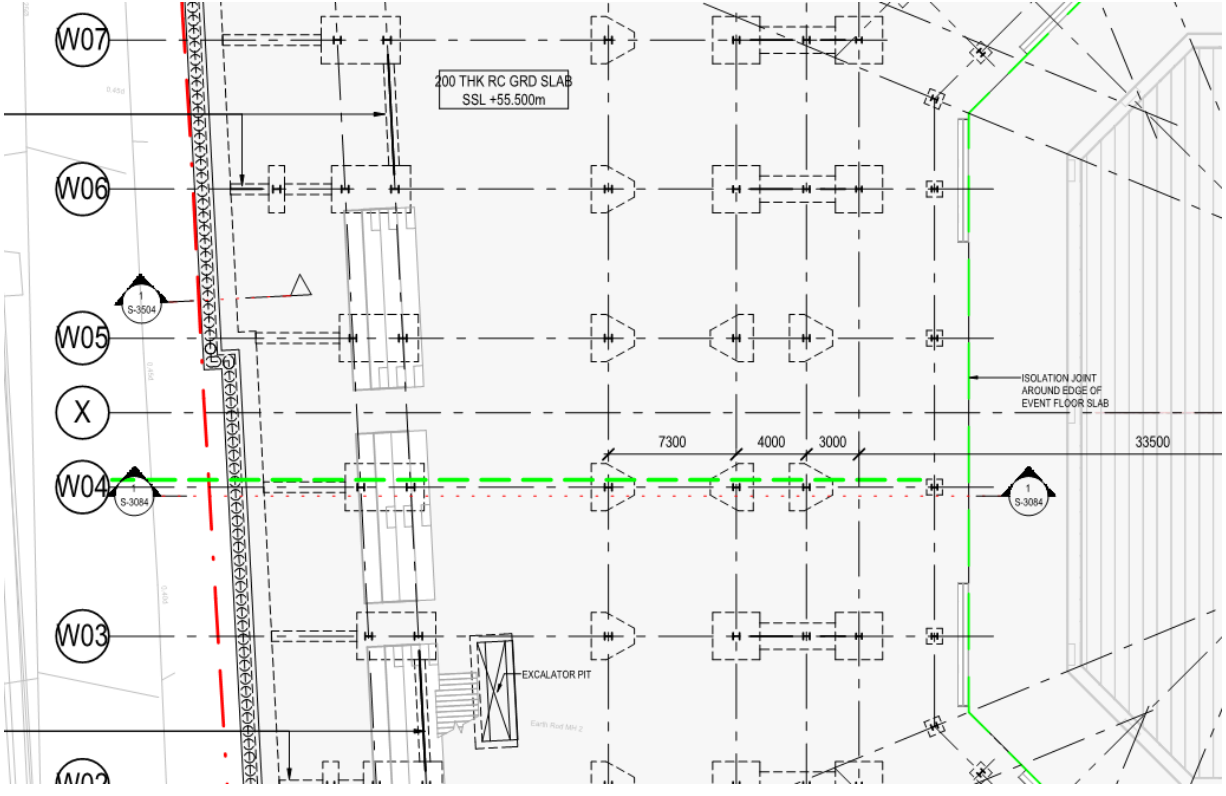
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Total Movements

Grid [m]	Pilecap Settlement [mm]	Span/360 (Variable Loads) [mm]	Total Acceptable Movement [mm]	Median Consolidation [mm]
6.5	10	18	28	25
7	10	19	29	25
7.5	10	21	31	25
8	10	22	32	25
8.5	10	24	34	25
9	10	25	35	25

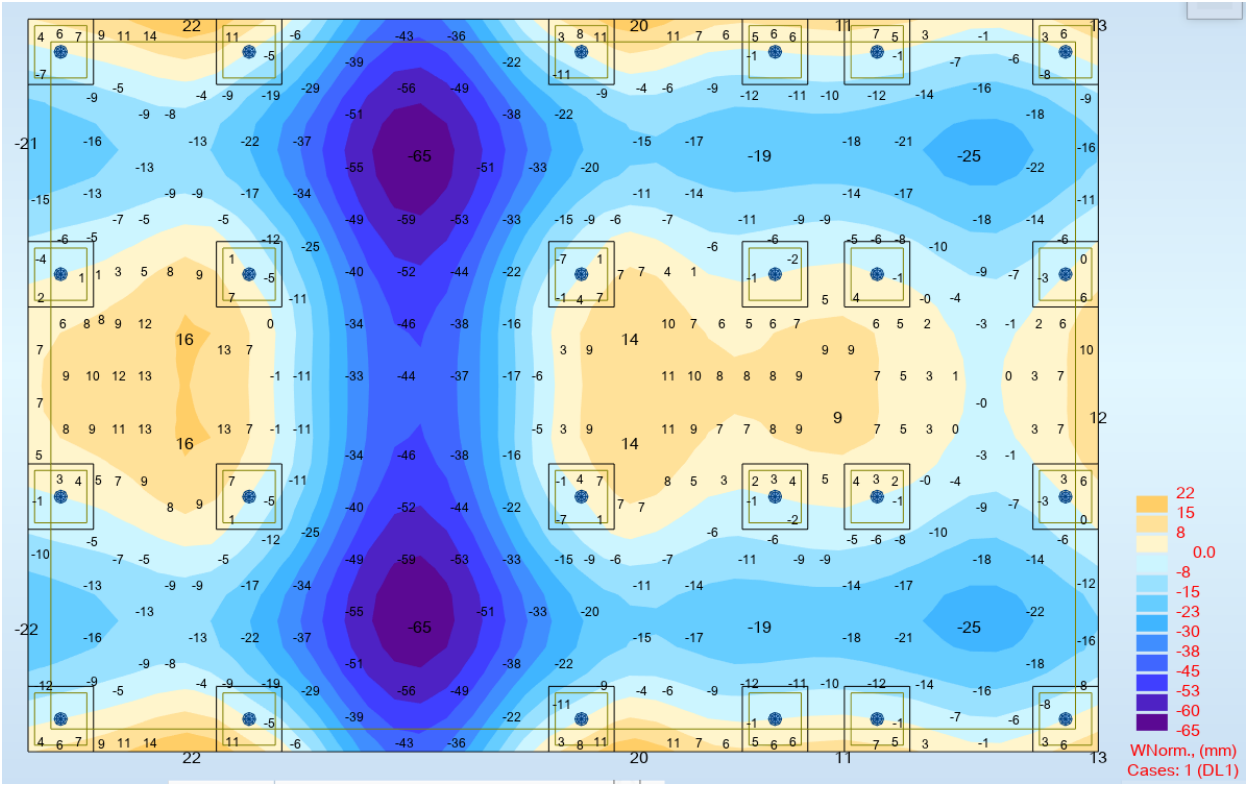
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Bay Analysis Study



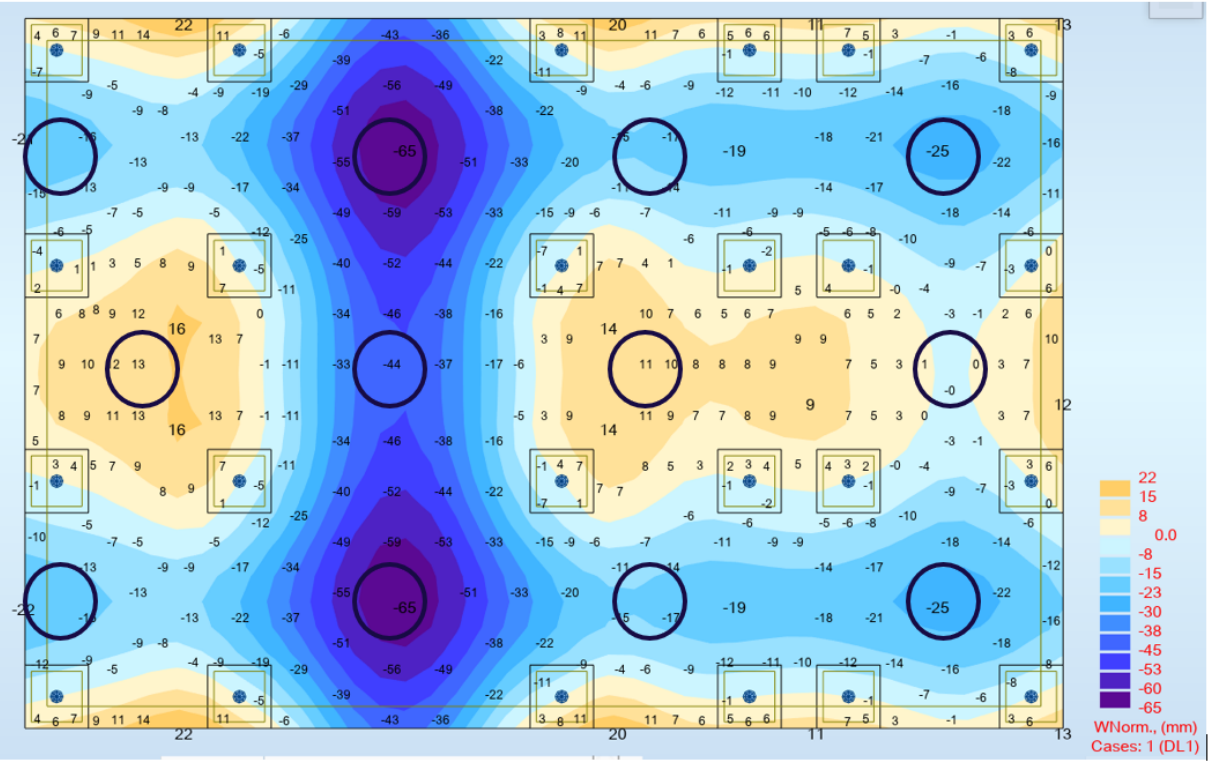
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Self-weight Settlement Analysis



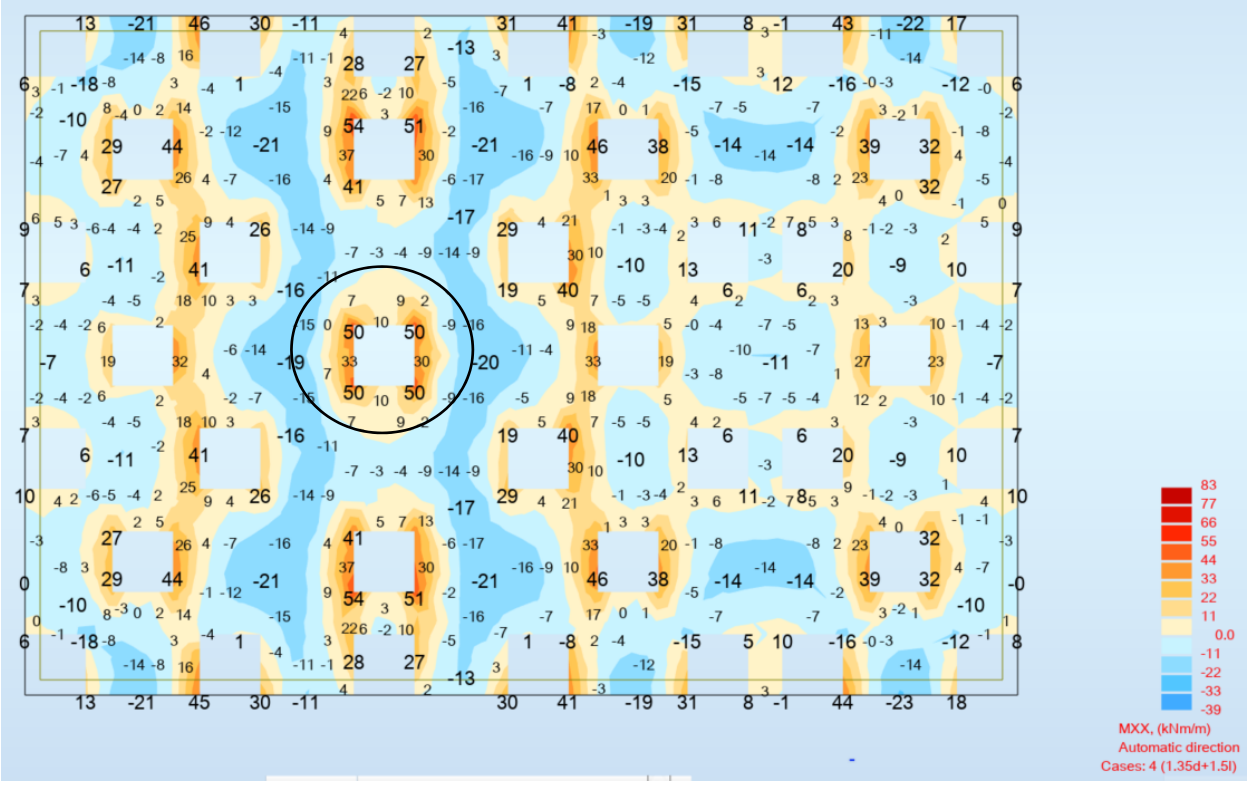
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Identifying Support Points (>15mm settlement)



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Bending Moments (Ultimate) – Typical Case



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Reinforcement Summary

General Areas (H10-100 Top Steel)

Section design to Eurocode 2 (BS EN 1992-1)

SOLID SLABS

Originated from TCC11.xlsm, v 4.7 on CD © 2003-2010 TCC

mpa The Concrete Centre

INPUT *Location* 1st Floor, Span H-J

M	kNm/m	50	f_{ck}	N/mm²	30	γ_c = 1.50
δ		1.00	f_{yk}	N/mm²	500	γ_s = 1.15
span	mm	3000	g_k	kN/m²	1.50	
h	mm	200	q_k	kN/m²	5.00	
Bar Ø	mm	10	Steel class		A	
cover, C_{nom}	mm	30	to this steel		Usage	Crowds
Δc_{dev}	mm	10	Section location			FLAT SLAB SPAN
			brittle partitions?			YES

OUTPUT **1st Floor, Span H-J**

d = 200 - 30 - 10/2 = 165.0 mm

3.1.7 (3) x = [165 - √(165² - 2000/0.85 x 50 x 1.5/30)]/0.8 = 23.6 mm

5.5 (4) (x/d) limit = 0.600 x/d actual = 0.143 < 0.600 ok

Fig 3.5 z = 165 - 0.4 x 23.6 = 155.5 mm

As = 50E6/500/155.5 x 1.15 = 739 > As min = 249 mm²/m

9.2.1.1 (1) As min = 1.51 x 165 = 249 mm²/m

As def = 739 mm²/m

Provide H10 @ 100 = 785 mm²/m

General Areas (H10-200 Bottom Steel)

Section design to Eurocode 2 (BS EN 1992-1)

SOLID SLABS

Originated from TCC11.xlsm, v 4.7 on CD © 2003-2010 TCC

mpa The Concrete Centre

INPUT *Location* 1st Floor, Span H-J

M	kNm/m	25	f_{ck}	N/mm²	30	γ_c = 1.50
δ		1.00	f_{yk}	N/mm²	500	γ_s = 1.15
span	mm	3000	g_k	kN/m²	1.50	
h	mm	200	q_k	kN/m²	5.00	
Bar Ø	mm	10	Steel class		A	
cover, C_{nom}	mm	30	to this steel		Usage	Crowds
Δc_{dev}	mm	10	Section location			FLAT SLAB SPAN
			brittle partitions?			YES

OUTPUT **1st Floor, Span H-J**

d = 200 - 30 - 10/2 = 165.0 mm

3.1.7 (3) x = [165 - √(165² - 2000/0.85 x 25 x 1.5/30)]/0.8 = 11.5 mm

5.5 (4) (x/d) limit = 0.600 x/d actual = 0.069 < 0.600 ok

Fig 3.5 z = 165 - 0.4 x 11.5 = 160.4 > 0.95d = 156

As = 25E6/500/156.8 x 1.15 = 367 > As min = 249 mm²/m

9.2.1.1 (1) As min = 1.51 x 165 = 249 mm²/m

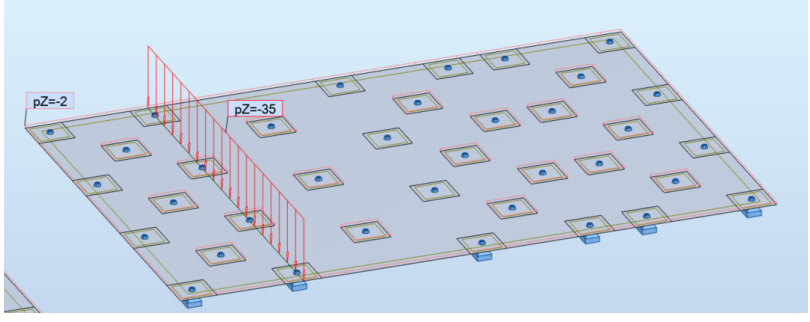
As def = 367 mm²/m

Provide H10 @ 200 = 393 mm²/m

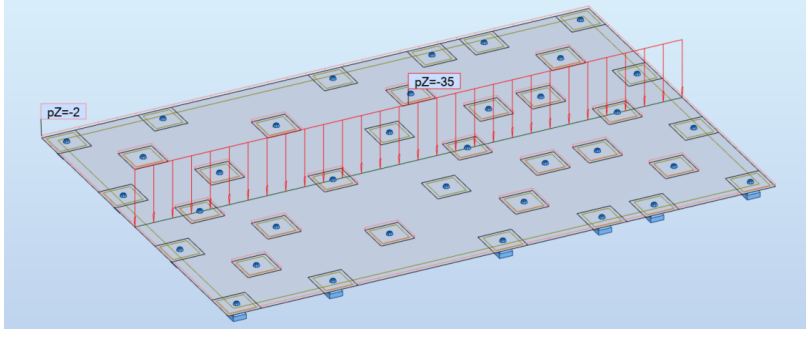
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Blockwork Wall Configurations

Across Column Strip



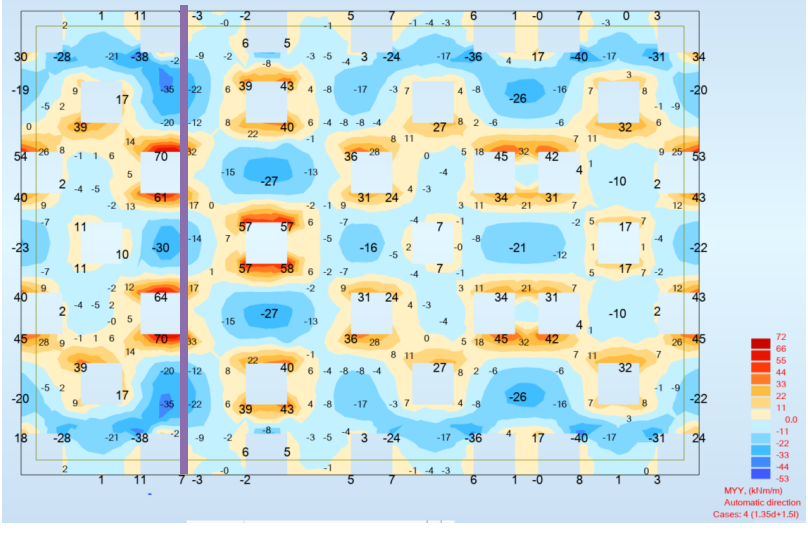
Across Middle Strip



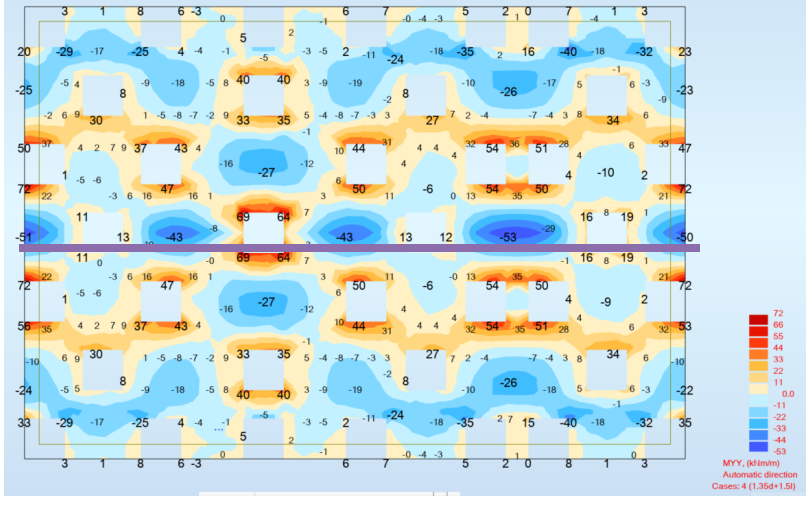
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Bending Moments

Across Column Strip



Across Middle Strip



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Reinforcement Summary

Top Steel (H12-100)

Section design to Eurocode 2 (BS EN 1992-1)

SOLID SLABS

eurocode Originated from TCC11.xlsm, v 4.7 on CD © 2003-2010 TCC

mpa The Concrete Centre

INPUT *Location* 1st Floor, Span H-J

M	kNm/m	70	f_{ck}	N/mm²	30	γ_c = 1.50
δ		1.00	f_{yk}	N/mm²	500	γ_s = 1.15
span	mm	3000	g_k	kN/m²	1.50	
h	mm	200	q_k	kN/m²	5.00	
Bar Ø	mm	12	Steel class		A	
cover, C_{nom}	mm	30	to this steel		Usage	Crowds
Δc_{dev}	mm	10	Section location			FLAT SLAB SPAN
			brittle partitions?			YES

OUTPUT 1st Floor, Span H-J .

d = 200 - 30 - 12/2 = 164.0 mm

3.1.7 (3) x = [164 - √(164² - 2000/0.85 x 70 x 1.5/30)]/0.8 = 34.2 mm

5.5 (4) (x/d) limit = 0.600 x/d actual = 0.209 < 0.600 ok

Fig 3.5 z = 164 - 0.4 x 34.2 = 150.3 mm .

As = 70E6/500/150.3 x 1.15 = 1071 > As min = 247 mm²/m

9.2.1.1 (1) As min = 1.51 x 164 = 247 mm²/m

As def = 1071 mm²/m

Provide H12 @ 100 = 1131 mm²/m

Bottom Steel (H10-100)

Section design to Eurocode 2 (BS EN 1992-1)

SOLID SLABS

eurocode Originated from TCC11.xlsm, v 4.7 on CD © 2003-2010 TCC

mpa The Concrete Centre

INPUT *Location* 1st Floor, Span H-J

M	kNm/m	50	f_{ck}	N/mm²	30	γ_c = 1.50
δ		1.00	f_{yk}	N/mm²	500	γ_s = 1.15
span	mm	3000	g_k	kN/m²	1.50	
h	mm	200	q_k	kN/m²	5.00	
Bar Ø	mm	10	Steel class		A	
cover, C_{nom}	mm	30	to this steel		Usage	Crowds
Δc_{dev}	mm	10	Section location			FLAT SLAB SPAN
			brittle partitions?			YES

OUTPUT 1st Floor, Span H-J .

d = 200 - 30 - 10/2 = 165.0 mm

3.1.7 (3) x = [165 - √(165² - 2000/0.85 x 50 x 1.5/30)]/0.8 = 23.6 mm

5.5 (4) (x/d) limit = 0.600 x/d actual = 0.143 < 0.600 ok

Fig 3.5 z = 165 - 0.4 x 23.6 = 155.5 mm .

As = 50E6/500/155.5 x 1.15 = 739 > As min = 249 mm²/m

9.2.1.1 (1) As min = 1.51 x 165 = 249 mm²/m

As def = 739 mm²/m

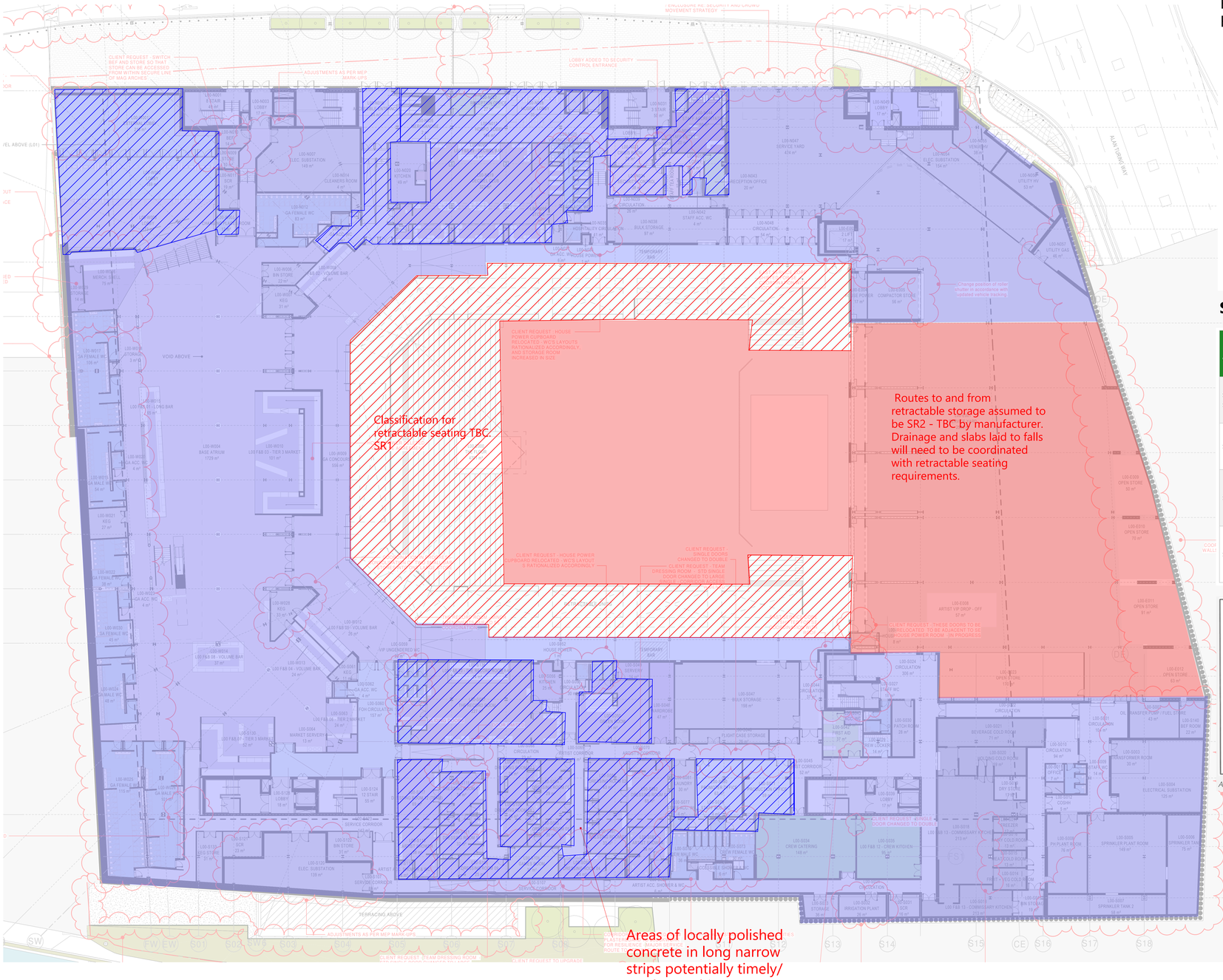
Provide H10 @ 100 = 785 mm²/m

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Appendix D Ground Slab Tolerances

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GROUND SLAB TOLERANCES



Retractable seating requirements to meet manufacturers requirements. At least SR1/ FM1

Forklift areas/ Retractable seating storage to manufacturers requirements. At least SR2/ FM2

Ordinary finish areas at SR2

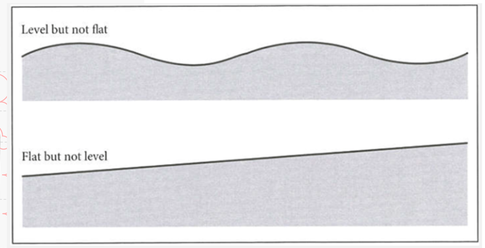
Suggested Areas at SR2

FM Classification = Free Movement Classification. Used for areas where vehicles, such as forklifts need to move freely without many obstacles.
Flatness and Levelness considered (floors laid to falls not suitable for FM classes)

Floor Class	Origins	Typical Floor Use	Additional	Typical Type of Laying Method
FM1	TR34 4th Edition	Where very high levels of flatness and levelness are required, sometimes called a 'superflat floor'. Used where forklift trucks are lifting over 13 meters high, also where high accuracy scientific equipment is used.	All points should be within +/- 15mm from Datum	Long, narrow eg. 5m strip construction with very accurate shuttering or permanent joints
FM2	TR34 4th Edition	Where high levels of flatness and levelness are required. Used where forklift trucks are lifting between 8 and 13 meters high. Most warehouses are now laid to this.	All points should be within +/- 15mm from Datum	Laser Screed or Screed Rail construction with very accurate shuttering or permanent joints
FM3	TR34 4th Edition	Where high levels of flatness and levelness are required. Used where forklift trucks are lifting up to 8 meters high. Also used where retail or manufacturing floors are recieving either no covering or a a very thin layer covering	All points should be within +/- 15mm from Datum	Laser Screed or Screed Rail construction with very accurate shuttering or permanent joints
FM4	TR34 4th Edition	Where low levels of flatness and levelness are required . Used where forklift trucks are lifting less than 4 meters high. Used where floor is to take additional layers of screed, insulation, tiles ect. Also for workshops and manufacturing floors	All points should be within +/- 15mm from Datum	Traditional Handlay method is sufficient, usually checked with laser level during pour
FM2 Special	TR34 3rd Edition	Where high levels of flatness and levelness are required initially, but where areas of the floor may be converted to having even higher level tolerance areas later in its life.	All points should be within +/- 15mm from Datum	Laser Screed or Screed Rail construction with very accurate shuttering or permanent joints

Surface Regularity = Mainly concerned with levelness

Floor Class	Origins	Typical Floor Use	Flatness Max gap under 2m Straightedge resting directly on the floor	Levelness (Any deflection will make the below invalid)	Typical Type of Laying Method
Special SR	BS 8204-2:2003 +A2:2011	Specialist tolerances can be agreed between Client, Designer, and Contractor	As Required	All points should be within +/- 15mm from planned level	Bespoke to project
SR1	BS 8204-2:2003 +A2:2011	Where very high levels of flatness s are required, as a finished floor or to take direct tiles	3 mm	All points should be within +/- 15mm from planned level	Laid with very low viscosity resins and free flowing screeds
SR2	BS 8204-2:2003 +A2:2011	Where high levels of flatness are required. Used where retail or manufacturing floors are recieving either no covering or a a very thin layer covering or very large floor tiles	5 mm	All points should be within +/- 15mm from planned level	Laid with resins or free flowing screeds, possibly with concrete in small, areas under ideal conditions
SR3	BS 8204-2:2003 +A2:2011	Where low levels of flatness and levelness are required . Used in external carparks and yards, where floor is to take additional layers of screed, insulation,carpet tiles ect. Also for workshops and manufacturing floors	10 mm	All points should be within +/- 15mm from planned level	Concrete can be laid in many ways to this, usually finished with powerfloats



As this exaggerated diagram shows, a floor may be level but not flat, or may be flat but not level.

BUROHAPPOLD ENGINEERING

STRUCTURES

Job Title:
OVG Manchester

Job Number:
042841

Sketch Title/Number:
Ground Slab Tolerances

Date: 29/06/20

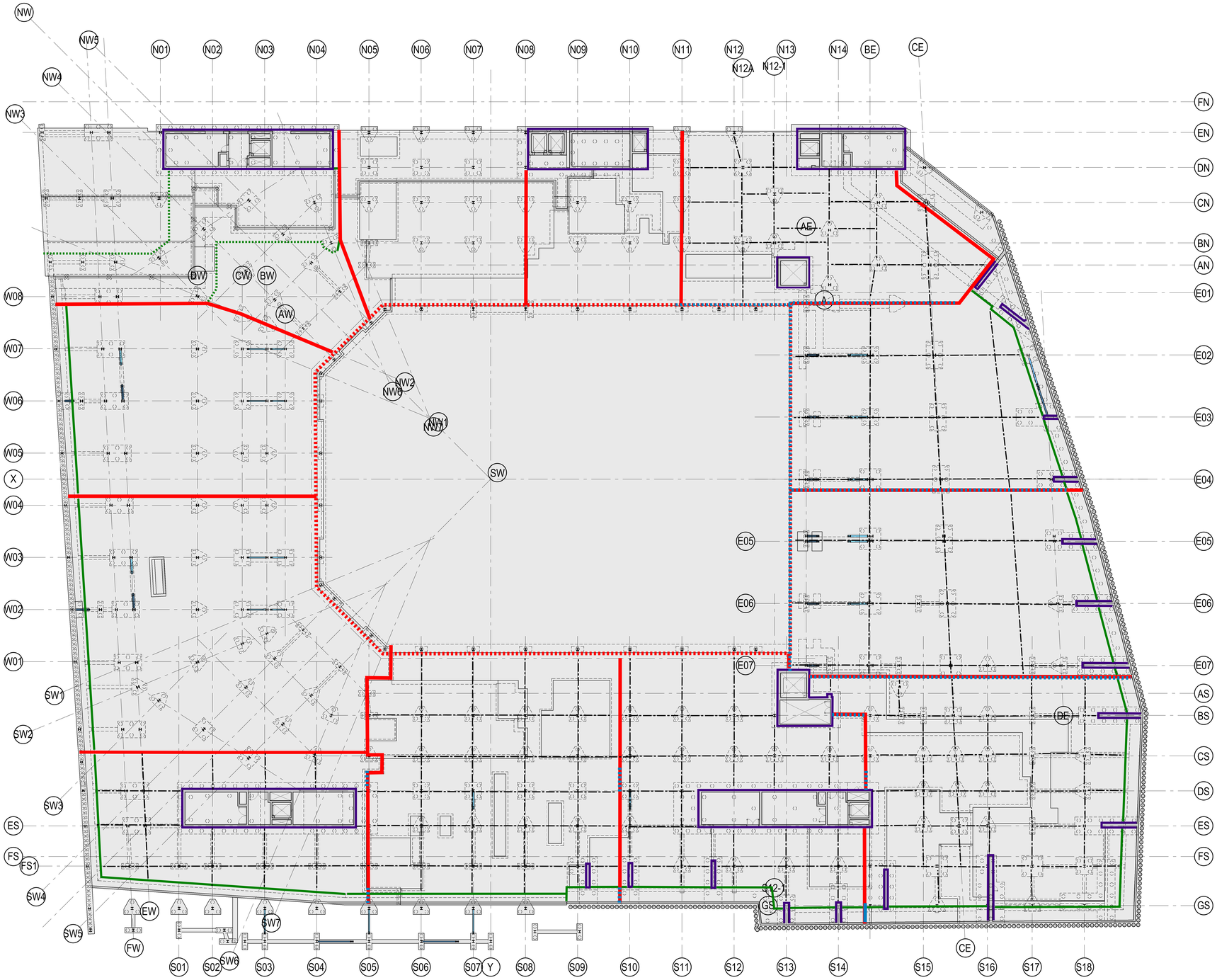
Initials: SL

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Appendix E Ground Slab Joints

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Ground Slab Floor Joints



- Free movement joint at locations with core and buttress walls
- Slab expansion joint
- Slab expansion joint at event floor edge thickening
- Tied joint
- Tied joint - North West Corner. Refer to Structural Details
- Armouring to Expansion and Tied joints required
- Saw cut joint. Still under development in terms of numbers, locations to be developed through 4b.

All steps in slab >500mm to have tied construction joint at top. Refer to Structural Details

BUROHAPPOLD ENGINEERING

STRUCTURES

Job Title:
Project Bradford

Job Number:
042841

Sketch Title/Number:
Ground Floor Slab Joints REV02

Date:	Initials:
01/07/20	SL

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