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Hall School

Structural Calculations

Basement – Preliminary

Job number.	2150206
Revision:	P1
Status:	Planning
Date:	March 2017

Document Control

		remarks:	Preliminary				
revision:	P1	prepared by:	Paul Stuart Davies BEng (Hons), MSc	checked by:	David Dempster MEng (Hons) (Cantab)	approved by:	James Souter MEng CEng MIStructE
date:	03/03/17	signature:		signature:		signature:	

Design Philosophy

The basement construction consists of two techniques:

1) New double height basement:

Construction, contiguous piled wall retaining wall, waterproof concrete liner wall – 200 to 250mm.

Design location; in all areas of new basement there will be a new intermediate slab, pile restrained by slabs at Ground, Basement 1 and Basement 2.

Design method: analysis of retaining wall as continuous member with pinned connections at slabs. Design of maximum moment for 450mm diameter RC column.

2) Underpinning of existing basement.

Reinforced concrete underpinning, width to match existing basement plus 250mm liner wall. Total width 625mm.

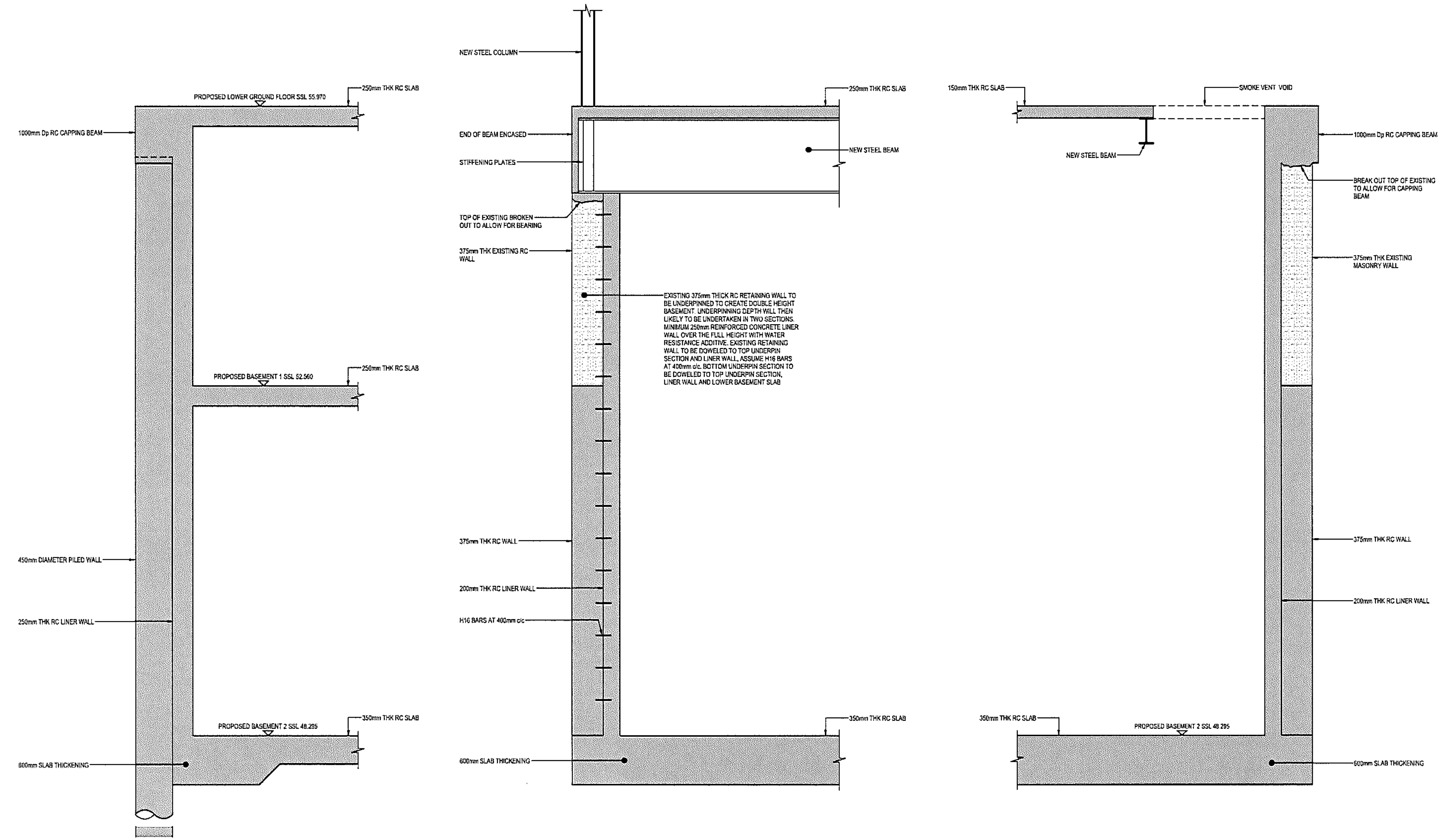
Design location; worst case is full double height basement restrained by slabs at Ground and Basement 2.

Design method: analysis of retaining wall propped at top and bottom. Design is conservative as it assumes full height clay and that the dead load surcharge acts at the top of the retained level.

Design Aids

Design Codes

Eurocode 1: BS EN 1991-1-1:2002	Actions on structures - Part 1-1: General actions - Densities, self-weight, imposed loads for buildings
Eurocode 2: BS EN 1992-1-1:2004	Design of concrete structures - Part 1-1: General rules and rules for buildings



SECTION 1-1
SCALE 1 : 25@A1

SECTION 2-2
SCALE 1 : 25@A1

SECTION 3-3
SCALE 1 : 25@A1

CONTIGWALL

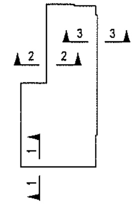
UNDERPINNED WALL.

This drawing is to be read in conjunction with all relevant architects, engineers and specialists drawings and specifications.

Do not scale from this drawing.

LEGEND

- EXISTING STRUCTURE
- NEW LOAD BEARING BLOCKWORK
- NEW LOAD BEARING BRICKWORK
- NEW REINFORCED CONCRETE
- NEW MASS CONCRETE
- PADSTONES
- LOAD BEARING STUDWORK
- NON LOAD BEARING WALLS
- LOAD BEARING STRUCTURE BELOW
- EXISTING STRUCTURE TO BE REMOVED
- NEW STEEL BEAMS
- NEW LINTELS OVER OPENINGS



KEY PLAN

NOT FOR CONSTRUCTION

P1	04.11.16	DPi	PSD	Issued for Planning
rev	date	by	chk	description

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project
The Hall School,
23 Crossfield Road,
Hampstead,
London NW3 4NU

drawing title
Proposed Boundary Wall Sections

scale (s)	date	drawn
1:25@A1;1:50@A3	October 2016	DPi

project no.			drawing status	
2150206			Preliminary	
originator	zone	level	role	drg no.	revision
EW	00	DET	S	2500	P1

Project name: HALL SCHOOL

Project number: Sheet: Revision:

Date: Engineer: Checked:

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BASEMENT - OUTLINE CALCS.

1) LOAD FROM NEIGHBOURING STRUCTURES. - 24 CROSSFIELD RD.

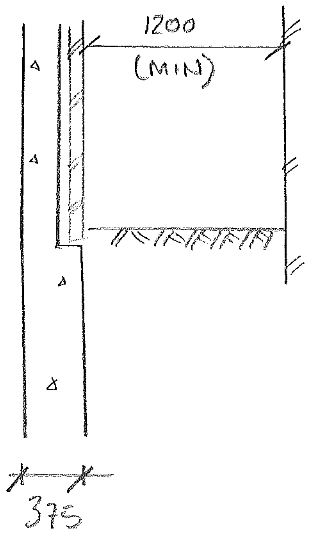
2) ANALYSIS OF CONTIG RETAINING WALL - LATERAL RESTRAINT @ MID POINT FROM FLOOR SLAB.

3) DESIGN CHECK OF CONTIG AS CIRCULAR COLUMN

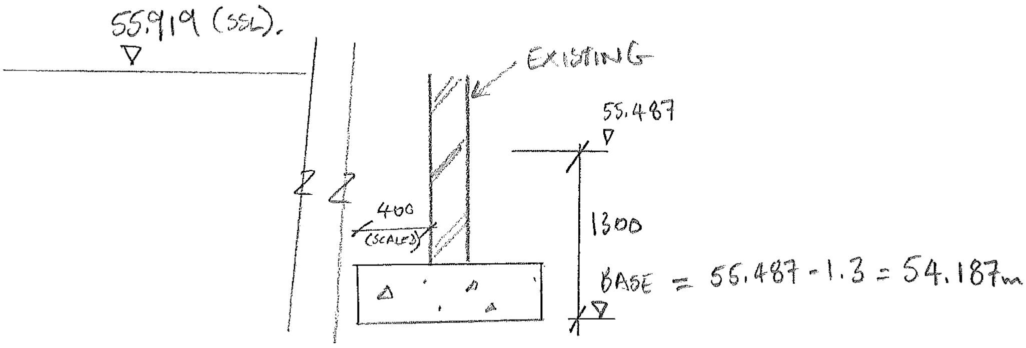
4) ANALYSIS & DESIGN OF RETAINING WALL. - FULL HEIGHT TO JUSTIFY THE UNDERPINNING.

1) NEIGHBOURING STRUCTURE – 1ST LOCATION OF NEIGHBOUR FROM ARCHIVE:

BASED ON ARCHIVE DRAWINGS; FRANK & LEWIN 8559/03 & 06.



FROM SECTION B-B ON 8559/06



FROM S-S ON 8559/03.

SEE ENCLOSED DRAWINGS.

Project name:

Project number: Sheet: Revision:

Date: Engineer: Checked:

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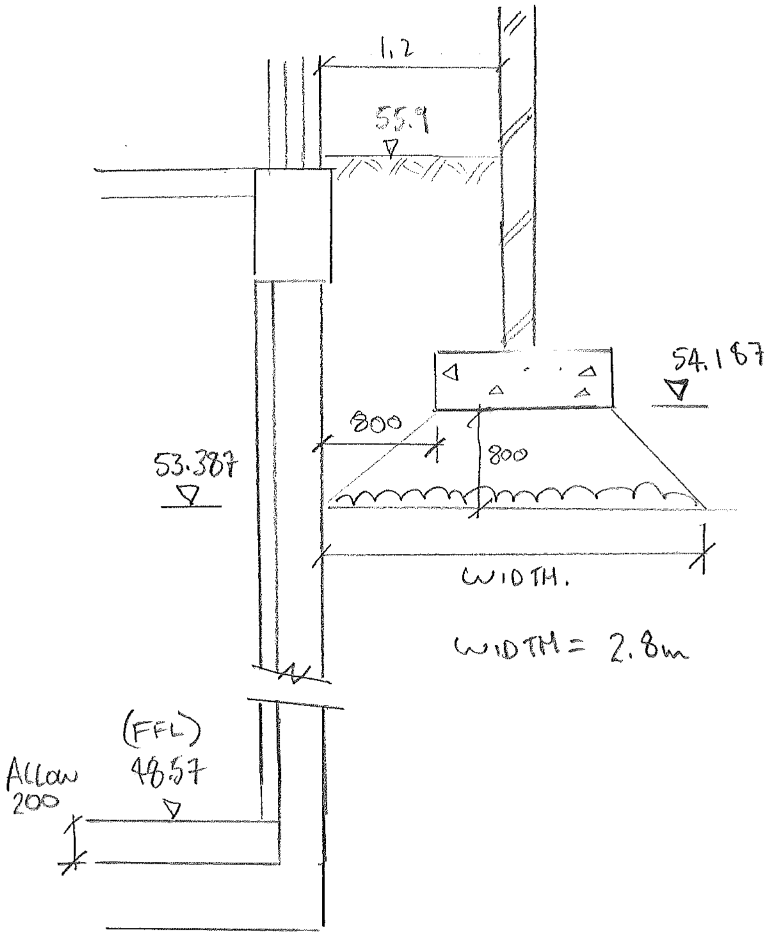
IF WE TAKE EXTERNAL = FFL = 55.9



LOAD FROM GARAGE FOUNDATION.

ALLOW DEAD LOAD ONLY AS 10kN/m² SURCHARGE WILL BE INCLUDED IN CALCS.

ROOF ALLOW

$1\text{kN/m}^2 \times \frac{4\text{m}}{2} = 2\text{kN/m}$

WALL

$19\text{kN/m}^3 \times 0.225 \times 3 = 12.8\text{kN/m}$

GROUND

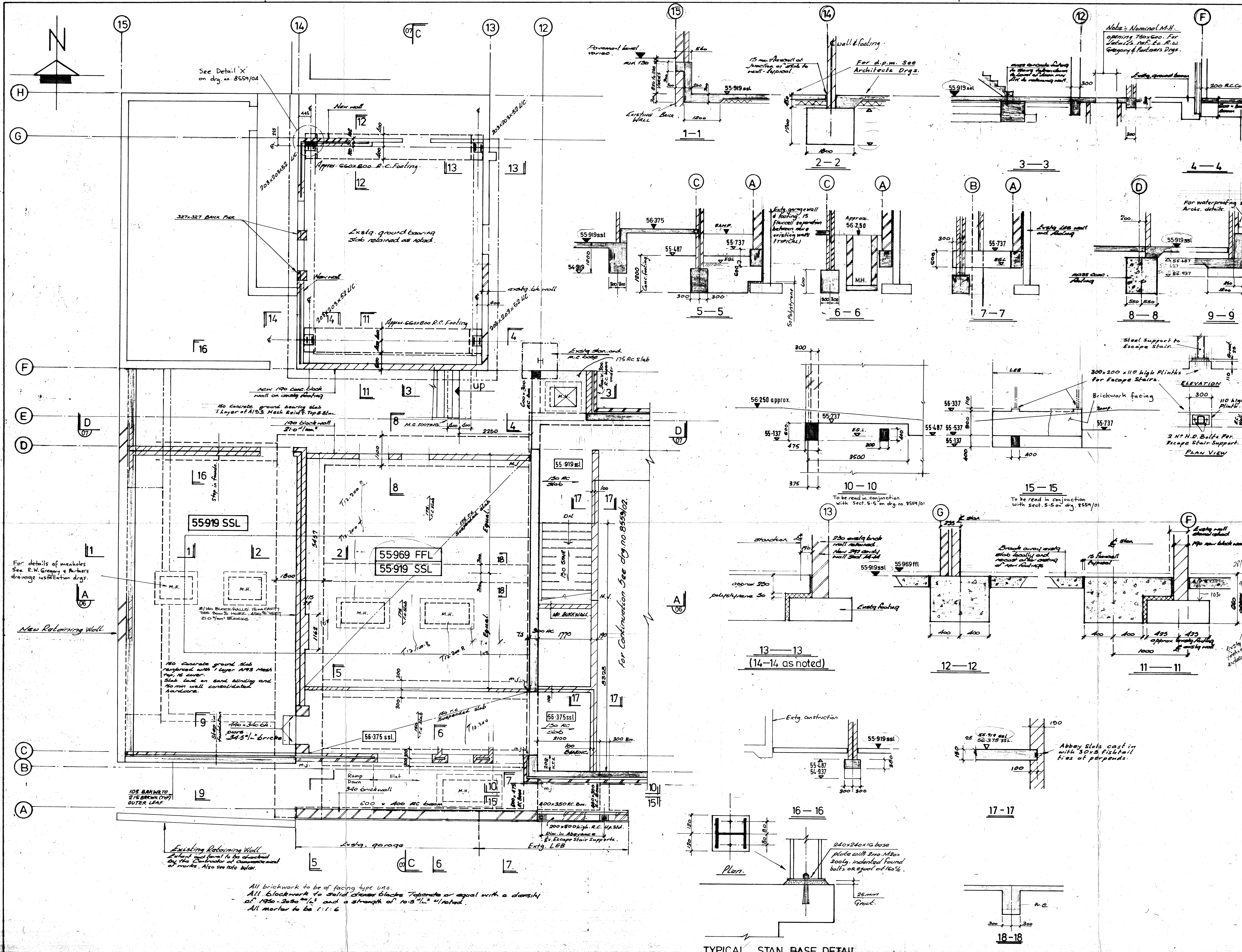
ASSUME GROUND BEARING SLAB ∴ NO REQUIREMENT AS < SOIL & NOT ON FOUNDS

TOTAL DL = 14.8kN/m

AS PRESSURE = $\frac{14.8}{2.8} = 5.3\text{kN/m}^2$

DL ON WALL = $5.3 \times 0.42 = 2.2\text{kN/m}$

STARTING ≈ 2m BELOW TOP



General Notes

1. THIS DRAWING TO BE READ IN CONJUNCTION WITH ALL RELEVANT ARCHITECTS AND ENGINEERS DETAILS.
2. For general notes see drg no. 8559/01.

ISSUED FOR CONSTRUCTION

FOR SECTION A—A TO D—D SEE DRG. NO. 8559/06 & 07.

Refer to Architects drgs. for all setting out dimensions

Revision	Description
J	RETAINING WALL GRIDS 15 & B REVISED TO SUIT ESTABLISHED SITE CONDITIONS
H	STAIRS AT ℄'s F/13 & ADJ. ℄ 13/C-D REVISED IN ACCORDANCE WITH ARCHITECTS REQUIREMENTS.
G	LEVELS CHANGED. 300 BLOCK REVISED TO 2/140 CAVITY WALL
F	327sq. pier shown on Grid Line 14/F-G.
E	Amended for Contract Issue
D	Stan. Base Detail Added + Min. Amend's.
C	Founds adjacent ramp adjusted. Drainage added
B	Revised in accordance with latest Architects and services requirements.
A	Minor revisions Issued for Building reg. approval.

Date	3.4.87	15.4.87	16.6.87	14.7.87	29.7.87	11.8.87	6.10.87	4.12.87	3.2.88	26/2/88								
Revision		A	B	C	D	E	F	G	H	J	K	L	M	N	P	R	S	T
Client						2												
Architect	1	1	1	1	1	1	8	8	8	8								
Quantity Surveyor	1	1	2	2	2	3												
Contractor H.O.				2	2													
" S.O									1	2								
M & E. Consultant	1	1	1	1	1													
Mech. Engineer																		
Elecl. (LEB)					1													
Local Authority		1		1		1		1	1	1								
Project Manager																		

Issued 13/8/87 O

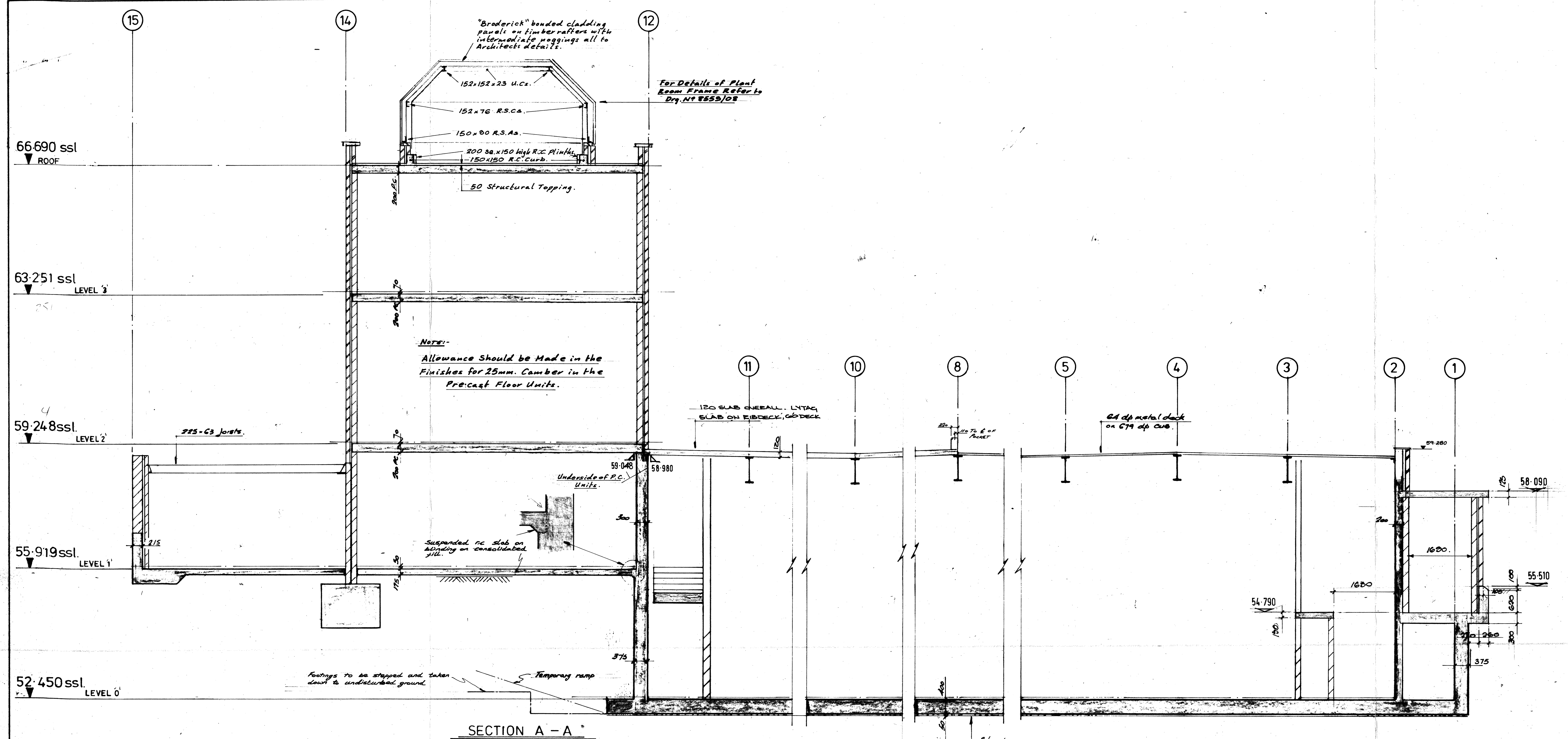
Franks and Lewin
Consulting Civil and Structural Engineers
21 Bloomsbury Way, London, WC1A 2TH Tel: 01-242 7943

Job: THE HALL SCHOOL HAMPSTEAD EXTENSION PHASE TWO.

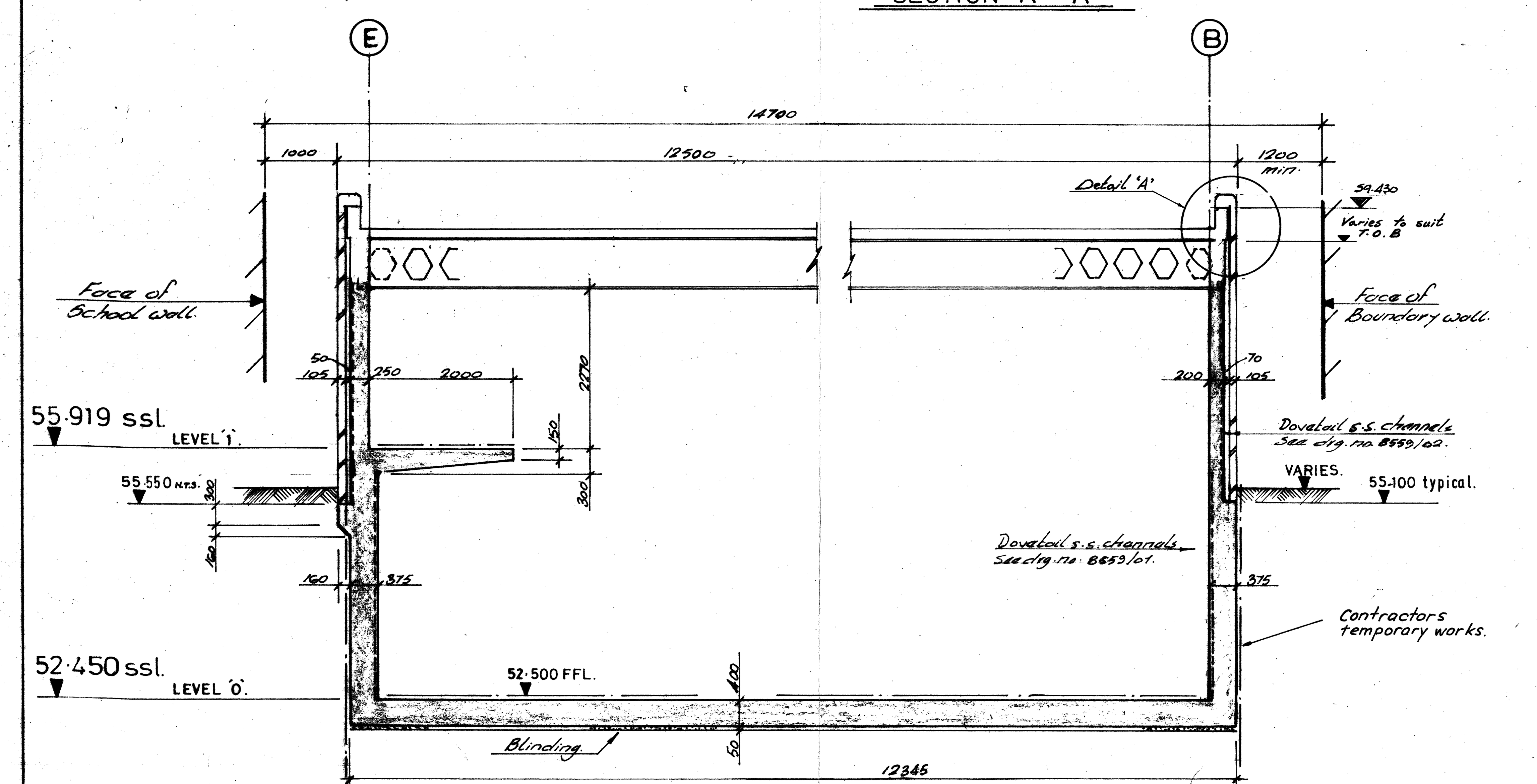
Drawing: THREE STOREY BLOCK & EXTENSION LEVEL 1. FOUNDATIONS — G.A.

Architect: Michael Haskoll Associates

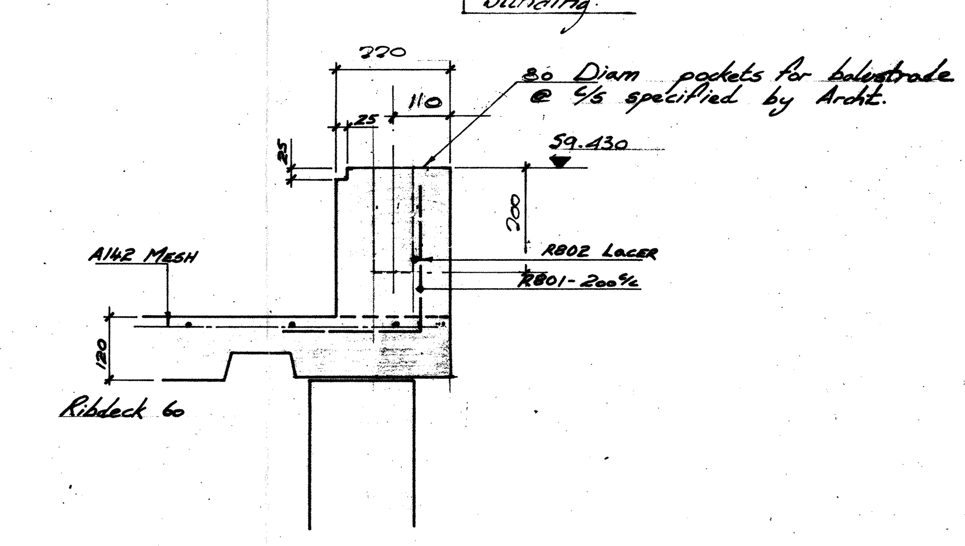
Scale: 1:50 1:20
Drawn: S.F.A.
Checked: CA
Drawing Number: 8559/03
Revision: J



SECTION A – A



SECTION B – B



Detail 'A'

General Notes

1. THIS DRAWING TO BE READ IN CONJUNCTION WITH ALL RELEVANT ARCHITECTS AND ENGINEERS DETAILS.
2. For general notes see drg. no. 8559/01.

ISSUED FOR CONSTRUCTION

Revision	Description
H	LEVELS AMENDED BETWEEN ¢'s 12-14 TO SUIT REVISED FINISH REQUIREMENTS. DETAIL 'A' REVISED STAIRS BETWEEN ¢'s 1-2 AND 11-12 REVISED.
G	LEVELS CHANGED + REVISIONS TO ROOF OF SECTIONS A-A + B-B
F	Amended for Contract Issue
E	Stairs on G.Ls. 1 & 12 Revised to Arch's. Detail
D.	Roof enclosure added. Hall stairs gr 1-2 revised.
C	Plant Room Roof Details added and other revisions to Architects details.
B	Revised in accordance with latest Architects and services requirements
A	Minor revisions. Issued for Building requirement approval.

Date	3.4.87	15.4.87	16.6.87	14.7.87	15.7.87	29.7.87	11.8.87	8/12/87	3/2/88									
Revision		A	B	C	D	E	F	G	H	J	K	L	M	N	P	R	S	T
Client																		
Architect	1	1	1			1	1	8	8									
Quantity Surveyor	1	1	2			2	3											
Contractor H.O.						[illegible]												
" S.O									1									
M & E. Consultant	1	1	1			1												
Mech. Engineer																		
Elecl. "																		
Local Authority		1					1	1	1									
Project Manager																		
Issued 13/8/87							0											

Franks and Lewin
Consulting Civil and Structural Engineers
21 Bloomsbury Way, London, WC1A 2TH Tel: 01-242 7943

Job
THE HALL SCHOOL HAMPSTEAD EXTENSION PHASE TWO.

Drawing
SECTIONS A–A & B–B.

Architect: Michael Haskoll Associates.
Scale: 1:50
Drawn: S.F.A.
Checked: CA.
Drawing Number: 8559/06
Revision: H

Project name: HALL SCHOOL.

Project number: Sheet: Revision:

Date: Engineer: Checked:

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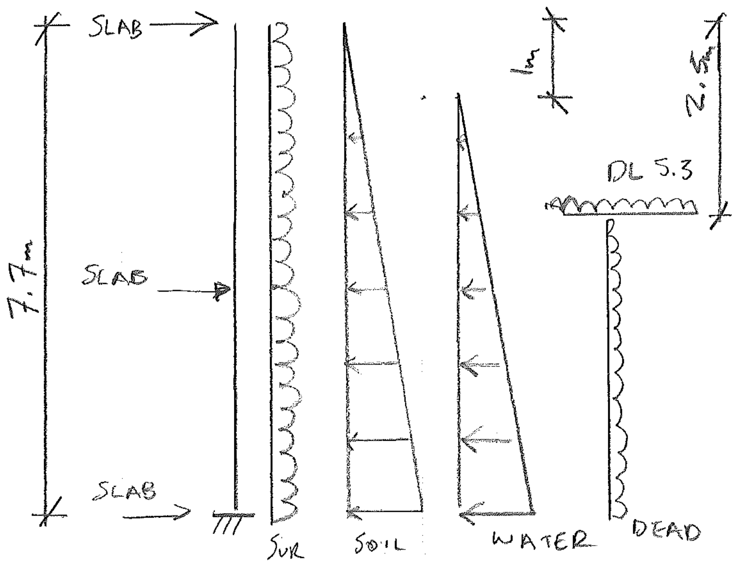
CHECK PILE AS CIRCULAR COLUMN.



SOIL:

$\phi = 24$

$ka = \dfrac{1 - \sin 24}{1 + \sin 24} = 0.42$

19.8 kN/m³

SUR = 10 × 0.42 = 4.2 kN/m (PERM)

SOIL = 19.8 × 0.42 × 7.7 = 64 kN/m (MAX). (PERM)

WATER = 10 × 6.7 = 67 kN/m (MAX). (PERM).

DEAD = 5.3 × 0.42 = 2.23 kN/m (PERM).

FOS:

SUR = 1.5

SOIL = 1.40

WATER = 1.35

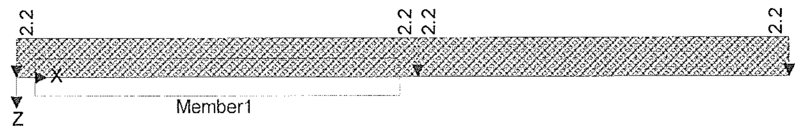
DEAD = 1.35.

SEE ANALYSIS OVER FOR 1m WIDTH.

ASSUME PILES @ 550mm ∴ ANALYSIS M × 0.55.

SEE 450 Ø PILE DESIGN IN TEDDS.

Dead - Loading



Load cases

Name	Enabled	Self weight factor	Patternable
Self Weight	yes	1	no
soil	yes	0	no
surcharge	yes	0	no
water	yes	0	no
Dead	yes	0	no

Load combinations

Load combination	Type	Enabled	Patterned
LoadCombination1	Strength	yes	no
LoadCombination2	Service	yes	no

Load combination: LoadCombination1 (Strength)

Load case	Factor
soil	1.4
surcharge	1.5
water	1.35
Dead	1.35

Load combination: LoadCombination2 (Service)

Load case	Factor
Self Weight	1
soil	1
surcharge	1
water	1
Dead	1

Element UDL loads

Element	Load case	Position			Load	Orientation
		Type	Start	End	(kN/m)	
1	surcharge	Ratio	0	1	4.2	GlobalZ
2	surcharge	Ratio	0	1	4.2	GlobalZ
1	Dead	Ratio	0	1	2.2	GlobalZ
2	Dead	Ratio	0	1	2.2	GlobalZ

Element VDL loads

Element	Load case	Position			Load		Orientation
		Type	Start	End	Start (kN/m)	End (kN/m)	
1	soil	Ratio	0	1	64	30.75	GlobalZ

Tekla Tedds	Project Hall School	Job no. 2150206
	Calcs for Retaining Wall - 1m width Analysis	Start page no./Revision 3
	Calcs by: PSD · Calcs date: 28/02/2017 · Checked by · Checked date	Approved by · Approved date

Element	Load case	Position			Load		Orientation
		Type	Start	End	Start (kN/m)	End (kN/m)	
2	soil	Ratio	0	1	30.75	0	GlobalZ
1	water	Ratio	0	1	67	27	GlobalZ
2	water	Absolute	0 m	2.7 m	27	0	GlobalZ

Results

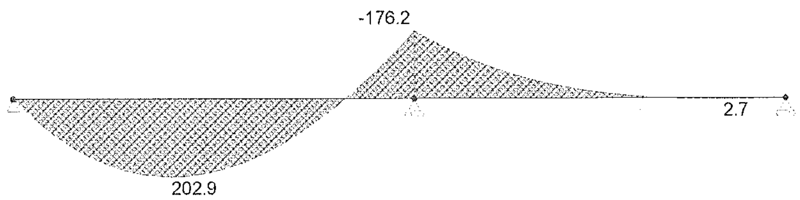
Forces

Element results

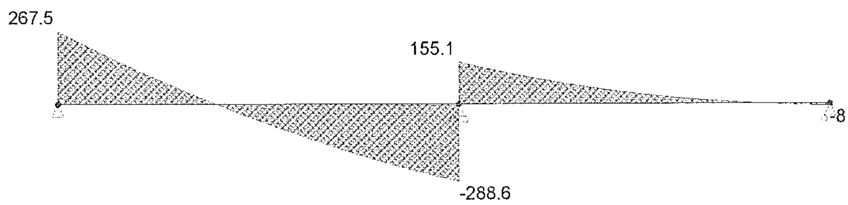
Envelope - Strength combinations

Element	Shear force		Moment			
	Pos (m)	Max abs (kN)	Pos (m)	Max (kNm)	Pos (m)	Min (kNm)
1	4	-288.6	1.579	202.9	4	-176.2
2	0	155.1	3.077	2.7	0	-176.2

LoadCombination1 (Strength) - Moment (kNm)



LoadCombination1 (Strength) - Shear (kN)



Element results

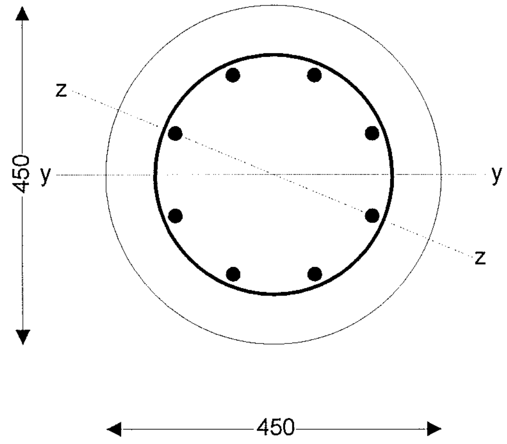
Load combination: LoadCombination1 (Strength)

Element	Shear force		Moment			
	Pos (m)	Max abs (kN)	Pos (m)	Max (kNm)	Pos (m)	Min (kNm)
1	4	-288.6	1.579	202.9	4	-176.2
2	0	155.1	3.077	2.7	0	-176.2

RC COLUMN DESIGN

In accordance with EN1992-1-1:2004 incorporating Corrigendum January 2008 and the UK national annex

Tedds calculation version 1.2.14



8 no. 20 mm diameter longitudinal bars

12 mm diameter links

Max link spacing 400 mm generally, 240 mm for 450 mm above and below slab/beam and at laps

Column geometry

Overall diameter h= **450** mm

Concrete details

Cylinder strength of concrete f_{ck} = **40** MPa — Safety factor for concrete γ_C = **1.50**

Coefficient α_{cc} — α_{cc} = **0.85**

Maximum aggregate size d_g = **20** mm

Reinforcement details

Nominal cover to links c_{nom} = **60** mm — Longitudinal bar diameter ϕ = **20** mm

Link diameter ϕ_v = **12** mm — Total no. of longitudinal bars N = **8**

Area of longitudinal reinft A_s = **2513** mm^2 — Safety factor for reinforcement γ_S = **1.15**

Modulus of elasticity of reinft E_s = **200000** MPa

Fire resistance details

Fire resistance period R = **60** min — Exposure to fire **More than one side**

Ratio of fire design axial load to design resistance μ_{fi} = **0.70**

Check nominal cover for fire and bond requirements

Min cover to links for bond $c_{min,b}$ = **12** mm — Min axis distance for fire a_{fi} = **40** mm

Allowance for deviations Δc_{dev} = **10** mm — Min allowable nominal cover c_{nom_min} = **22.0** mm

PASS - the nominal cover is greater than the minimum required

Key points on interaction diagram for bending about y axis

Axial load capacity no mt N_{Rd0} = **4073** kN

Axial no strain in tension reinft N_{Rdy1} = **2733** kN — Mt no strain in tension reinft M_{Rdy1} = **180.1** kNm

Axial conc/tension steel at yield N_{Rdy2} = **1115** kN — Mt conc/tension steel at yield M_{Rdy2} = **223.4** kNm

Mt capacity no axial load M_{Rdy3} = **151.2** kNm

Axial at additional location N_{Rdy4} = **3507** kN — Mt at additional location M_{Rdy4} = **112.5** kNm

Key points on interaction diagram for bending about z axis

Axial load capacity no mt N_{Rd0} = **4073** kN

Axial no strain in tension reinft N_{Rdz1} = **2848** kN — Mt no strain in tension reinft M_{Rdz1} = **173.2** kNm

Axial conc/tension steel at yield N_{Rdz2} = **1219** kN

Mt conc/tension steel at yield M_{Rdz2} = **222.8** kNm

Mt capacity no axial load M_{Rdz3} = **154.7** kNm

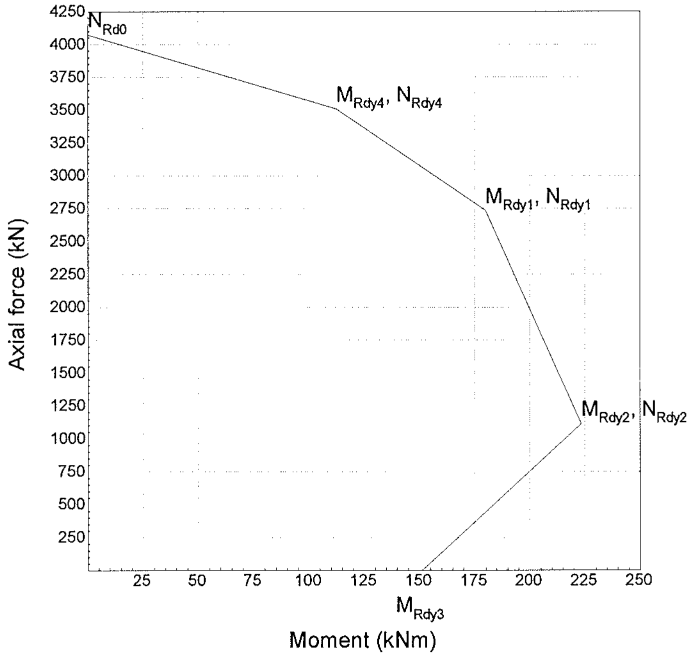
Axial at additional location N_{Rdz4} = **3587** kN

Mt at additional location M_{Rdz4} = **99.6** kNm

Tekla Tedds	Project Hall School			Job no. 2150206	
	Calcs for Retaining Wall - Pile as Column			Start page no./Revision 3	
	Calcs by PSD	Calcs date 20/02/2017	Checked by	Checked date	Approved by	Approved date

Interaction diagram for bending about y axis

450 mm diameter column, 8 no. 20 mm longitudinal bars



N_{Rd0} = 4073 kN

M_{Rdy1} = 180 kNm N_{Rdy1} = 2733 kN

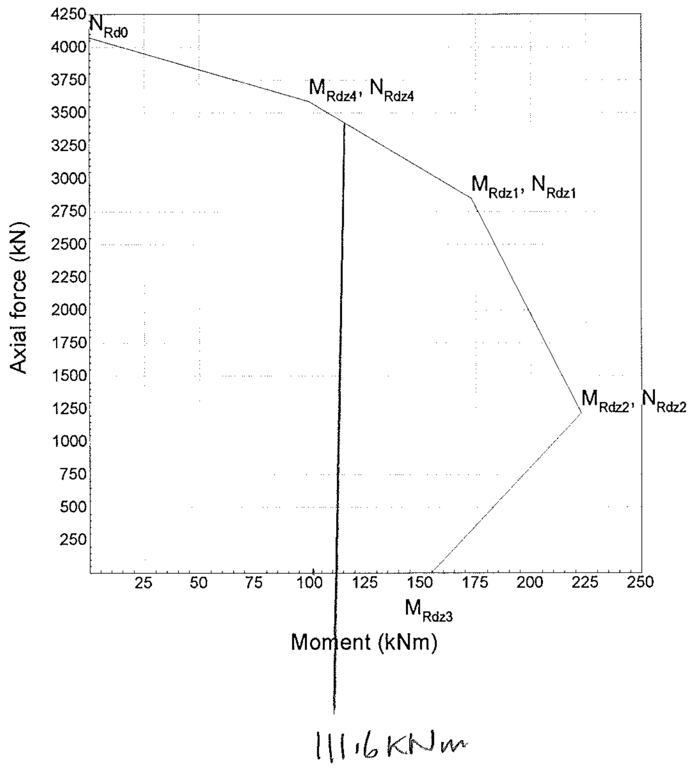
M_{Rdy2} = 223 kNm N_{Rdy2} = 1115 kN

M_{Rdy3} = 151 kNm N_{Rdy3} = 0kN

M_{Rdy4} = 113 kNm N_{Rdy4} = 3507 kN

Interaction diagram for bending about z axis

450 mm diameter column, 8 no. 20 mm longitudinal bars



N_{Rd0} = 4073 kN

M_{Rdz1} = 173 kNm N_{Rdz1} = 2848 kN

M_{Rdz2} = 223 kNm N_{Rdz2} = 1219 kN

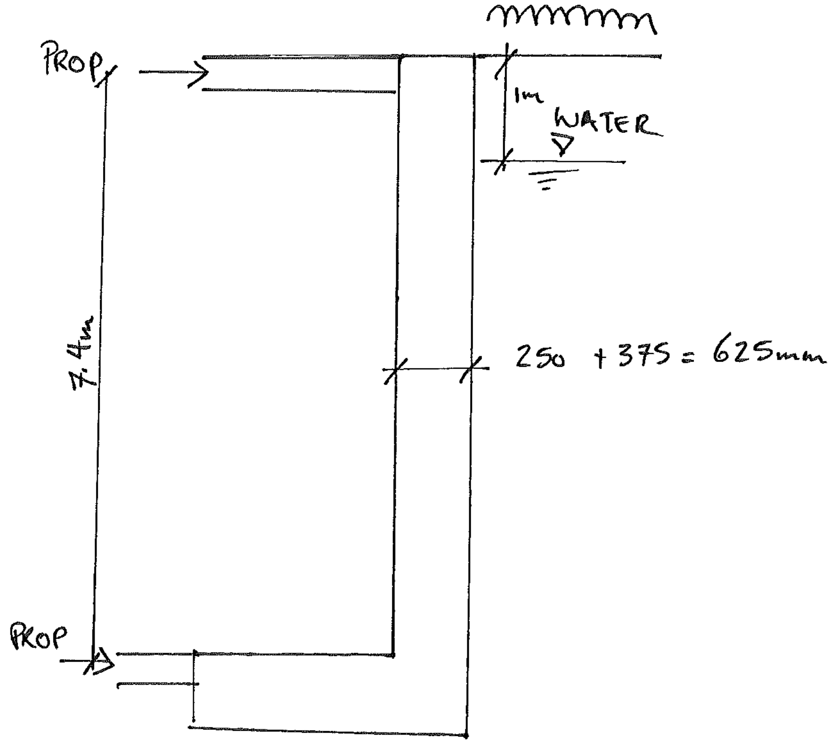
M_{Rdz3} = 155 kNm N_{Rdz3} = 0kN

M_{Rdz4} = 100 kNm N_{Rdz4} = 3587 kN

m = 202.9 x 0.55

m = 111.6 kNm

SURCHARGE LL = 10 kN/m²
DL = 5.3 kN/m² *



Ø = 24°
CLAY
19.62 kN/m³

* FOR SIMPLICITY APPLY SURCHARGE FROM FOUNDATION

SEE TEDDS OVER FOR DESIGN & ANALYSIS.

OUTLINE CALCULATION SUBJECT TO DETAILED DESIGN.

RETAINING WALL ANALYSIS

In accordance with EN1997-1:2004 incorporating Corrigendum dated February 2009 and the UK National Annex incorporating Corrigendum No.1

Tedds calculation version 2.6.09

Retaining wall details

Stem type	Propped cantilever
Stem height	h_{stem} = **7400** mm
Prop height	h_{prop} = **7400** mm
Stem thickness	t_{stem} = **625** mm
Angle to rear face of stem	α = **90** deg
Stem density	γ_{stem} = **25** kN/m^3
Toe length	l_{toe} = **1500** mm
Base thickness	t_{base} = **500** mm
Base density	γ_{base} = **25** kN/m^3
Height of retained soil	h_{ret} = **7400** mm
Angle of soil surface	β = **0** deg
Depth of cover	d_{cover} = **0** mm
Height of water	h_{water} = **6400** mm
Water density	γ_w = **9.8** kN/m^3

Retained soil properties

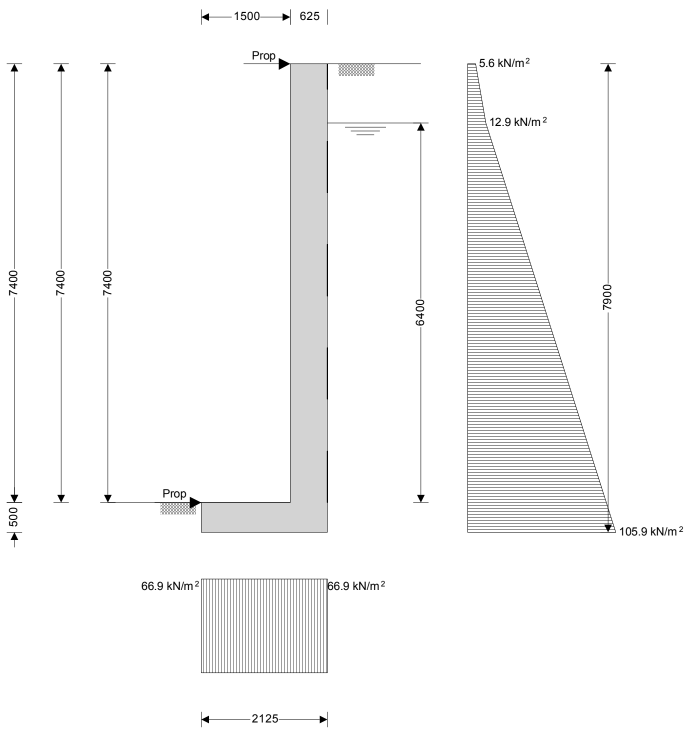
Soil type	Stiff clay
Moist density	γ_{mr} = **19.6** kN/m^3
Saturated density	γ_{sr} = **19.6** kN/m^3
Characteristic effective shear resistance angle	$\phi'_{r.k}$ = **24** deg
Characteristic wall friction angle	$\delta_{r.k}$ = **12** deg

Base soil properties

Soil density	γ_b = **19.6** kN/m^3
Characteristic effective shear resistance angle	$\phi'_{b.k}$ = **24** deg
Characteristic wall friction angle	$\delta_{b.k}$ = **12** deg
Characteristic base friction angle	$\delta_{bb.k}$ = **12** deg
Presumed bearing capacity	$P_{bearing}$ = **200** kN/m^2

Loading details

Permanent surcharge load	$Surcharge_G$ = **5** kN/m^2
Variable surcharge load	$Surcharge_Q$ = **10** kN/m^2



General arrangement

Calculate retaining wall geometry

Base length	$l_{base} = l_{toe} + t_{stem} = \mathbf{2125}$ mm
Saturated soil height	$h_{sat} = h_{water} + d_{cover} = \mathbf{6400}$ mm
Moist soil height	$h_{moist} = h_{ret} - h_{water} = \mathbf{1000}$ mm
Length of surcharge load	$l_{sur} = l_{heel} = \mathbf{0}$ mm
- Distance to vertical component	$x_{sur\_v} = l_{base} - l_{heel} / 2 = \mathbf{2125}$ mm
Effective height of wall	$h_{eff} = h_{base} + d_{cover} + h_{ret} = \mathbf{7900}$ mm
- Distance to horizontal component	$x_{sur\_h} = h_{eff} / 2 = \mathbf{3950}$ mm
Area of wall stem	$A_{stem} = h_{stem} \times t_{stem} = \mathbf{4.625}$ m^2
- Distance to vertical component	$x_{stem} = l_{toe} + t_{stem} / 2 = \mathbf{1813}$ mm
Area of wall base	$A_{base} = l_{base} \times t_{base} = \mathbf{1.063}$ m^2
- Distance to vertical component	$x_{base} = l_{base} / 2 = \mathbf{1063}$ mm

Using Coulomb theory

Active pressure coefficient: $K_A = \sin(\alpha + \phi'_{r.k})^2 / (\sin(\alpha)^2 \times \sin(\alpha - \delta_{r.k}) \times [1 + \sqrt{[\sin(\phi'_{r.k} + \delta_{r.k}) \times \sin(\phi'_{r.k} - \beta) / (\sin(\alpha - \delta_{r.k}) \times \sin(\alpha + \beta))]}]^2) = \mathbf{0.382}$

Passive pressure coefficient: $K_P = \sin(90 - \phi'_{b.k})^2 / (\sin(90 + \delta_{b.k}) \times [1 - \sqrt{[\sin(\phi'_{b.k} + \delta_{b.k}) \times \sin(\phi'_{b.k}) / (\sin(90 + \delta_{b.k}))]}]^2) = \mathbf{3.337}$

Bearing pressure check

Vertical forces on wall

Wall stem	$F_{stem} = A_{stem} \times \gamma_{stem} = \mathbf{115.6}$ kN/m
Wall base	$F_{base} = A_{base} \times \gamma_{base} = \mathbf{26.6}$ kN/m

Total	$F_{total\_v} = F_{stem} + F_{base} + F_{water\_v} =$ **142.2** kN/m

Horizontal forces on wall

Surcharge load	$F_{sur\_h} = K_A \times \cos(\delta_{r.d}) \times (Surcharge_G + Surcharge_Q) \times h_{eff} =$ **44.3** kN/m
Saturated retained soil	$F_{sat\_h} = K_A \times \cos(\delta_{r.d}) \times (\gamma_{sr}' - \gamma_w') \times (h_{sat} + h_{base})^2 / 2 =$ **87.3** kN/m
Water	$F_{water\_h} = \gamma_w' \times (h_{water} + d_{cover} + h_{base})^2 / 2 =$ **233.5** kN/m
Moist retained soil	$F_{moist\_h} = K_A \times \cos(\delta_{r.d}) \times \gamma_{mr}' \times ((h_{eff} - h_{sat} - h_{base})^2 / 2 + (h_{eff} - h_{sat} - h_{base}) \times (h_{sat} + h_{base})) =$ **54.3** kN/m
Base soil	$F_{pass\_h} = -K_P \times \cos(\delta_{b.d}) \times \gamma_b' \times (d_{cover} + h_{base})^2 / 2 =$ **-8** kN/m
Total	$F_{total\_h} = F_{sat\_h} + F_{moist\_h} + F_{pass\_h} + F_{water\_h} + F_{sur\_h} =$ **411.3** kN/m

Moments on wall

Wall stem	$M_{stem} = F_{stem} \times x_{stem} =$ **209.6** kNm/m
Wall base	$M_{base} = F_{base} \times x_{base} =$ **28.2** kNm/m
Surcharge load	$M_{sur} = -F_{sur\_h} \times x_{sur\_h} =$ **-174.9** kNm/m
Saturated retained soil	$M_{sat} = -F_{sat\_h} \times x_{sat\_h} =$ **-200.7** kNm/m
Water	$M_{water} = -F_{water\_h} \times x_{water\_h} =$ **-537.1** kNm/m
Moist retained soil	$M_{moist} = -F_{moist\_h} \times x_{moist\_h} =$ **-201.1** kNm/m
Total	$M_{total} = M_{stem} + M_{base} + M_{sat} + M_{moist} + M_{water} + M_{sur} =$ **-876** kNm/m

Check bearing pressure

Propping force to stem	$F_{prop\_stem} = (F_{total\_v} \times l_{base} / 2 - M_{total}) / (h_{prop} + t_{base}) =$ **130** kN/m
Propping force to base	$F_{prop\_base} = F_{total\_h} - F_{prop\_stem} =$ **281.3** kN/m
Moment from propping force	$M_{prop} = F_{prop\_stem} \times (h_{prop} + t_{base}) =$ **1027.1** kNm/m
Distance to reaction	$\bar{x} = (M_{total} + M_{prop}) / F_{total\_v} =$ **1063** mm
Eccentricity of reaction	$e = \bar{x} - l_{base} / 2 =$ **0** mm
Loaded length of base	$l_{load} = l_{base} =$ **2125** mm
Bearing pressure at toe	$q_{toe} = F_{total\_v} / l_{base} \times (1 - 6 \times e / l_{base}) =$ **66.9** kN/m^2
Bearing pressure at heel	$q_{heel} = F_{total\_v} / l_{base} \times (1 + 6 \times e / l_{base}) =$ **66.9** kN/m^2
Factor of safety	$FoS_{bp} = P_{bearing} / \max(q_{toe}, q_{heel}) =$ **2.989**

PASS - Allowable bearing pressure exceeds maximum applied bearing pressure

RETAINING WALL DESIGN

In accordance with EN1992-1-1:2004 incorporating Corrigendum dated January 2008 and the UK National Annex incorporating National Amendment No.1

Tedds calculation version 2.6.09

Concrete details - Table 3.1 - Strength and deformation characteristics for concrete

Concrete strength class	C40/50
Characteristic compressive cylinder strength	$f_{ck} =$ **40** N/mm^2
Characteristic compressive cube strength	$f_{ck,cube} =$ **50** N/mm^2
Mean value of compressive cylinder strength	$f_{cm} = f_{ck} + 8$ N/mm^2 = **48** N/mm^2
Mean value of axial tensile strength	$f_{ctm} = 0.3$ N/mm$^2 \times (f_{ck} / 1$ N/mm$^2)^{2/3}$ = **3.5** N/mm^2
5% fractile of axial tensile strength	$f_{ctk,0.05} = 0.7 \times f_{ctm} =$ **2.5** N/mm^2
Secant modulus of elasticity of concrete	$E_{cm} = 22$ kN/mm$^2 \times (f_{cm} / 10$ N/mm$^2)^{0.3}$ = **35220** N/mm^2
Partial factor for concrete - Table 2.1N	$\gamma_C =$ **1.50**
Compressive strength coefficient - cl.3.1.6(1)	$\alpha_{cc} =$ **0.85**
Design compressive concrete strength - exp.3.15	$f_{cd} = \alpha_{cc} \times f_{ck} / \gamma_C =$ **22.7** N/mm^2
Maximum aggregate size	$h_{agg} =$ **20** mm

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	Retaining Wall				4	
	Calcs by	Calcs date	Checked by	Checked date	Approved by	Approved date
	PSD	03/03/2017				

Reinforcement details

Characteristic yield strength of reinforcement f_{yk} = **500** N/mm^2

Modulus of elasticity of reinforcement E_s = **200000** N/mm^2

Partial factor for reinforcing steel - Table 2.1N γ_S = **1.15**

Design yield strength of reinforcement $f_{yd} = f_{yk} / \gamma_S$ = **435** N/mm^2

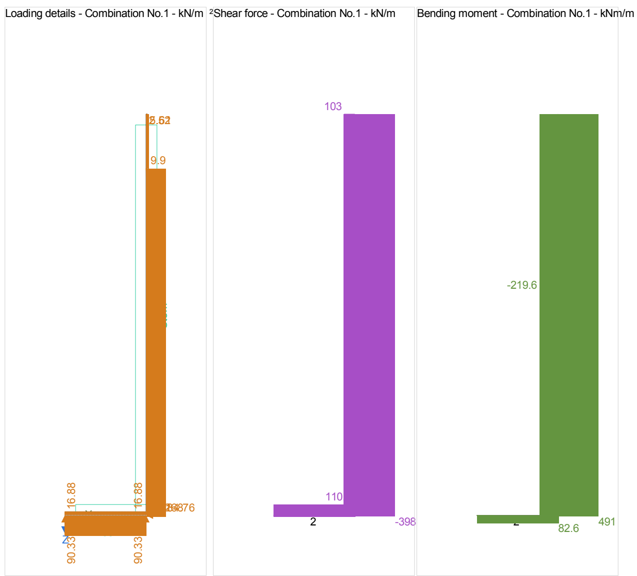
Cover to reinforcement

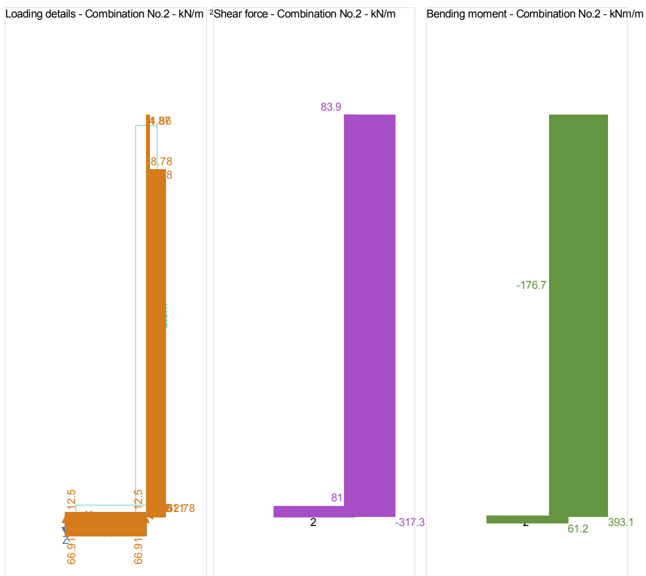
Front face of stem c_{sf} = **40** mm

Rear face of stem c_{sr} = **50** mm

Top face of base c_{bt} = **50** mm

Bottom face of base c_{bb} = **75** mm





Check stem design at 4094 mm

Depth of section h = **625** mm

Rectangular section in flexure - Section 6.1

Design bending moment combination 1 — M = **219.6** kNm/m

Depth to tension reinforcement — $d = h - c_{sf} - \phi_{sx} - \phi_{sfM} / 2$ = **555** mm

$K = M / (d^2 \times f_{ck})$ = **0.018**

K' = **0.207**

K' > K - No compression reinforcement is required

Lever arm — $z = \min(0.5 + 0.5 \times (1 - 3.53 \times K)^{0.5}, 0.95) \times d$ = **527** mm

Depth of neutral axis — $x = 2.5 \times (d - z)$ = **69** mm

Area of tension reinforcement required — $A_{sfM.req} = M / (f_{yd} \times z)$ = **958** mm^2/m

Tension reinforcement provided — 20 dia.bars @ 150 c/c

Area of tension reinforcement provided — $A_{sfM.prov} = \pi \times \phi_{sfM}^2 / (4 \times s_{sfM})$ = **2094** mm^2/m

Minimum area of reinforcement - exp.9.1N — $A_{sfM.min} = \max(0.26 \times f_{ctm} / f_{yk}, 0.0013) \times d$ = **1013** mm^2/m

Maximum area of reinforcement - cl.9.2.1.1(3) — $A_{sfM.max} = 0.04 \times h$ = **25000** mm^2/m

$\max(A_{sfM.req}, A_{sfM.min}) / A_{sfM.prov}$ = **0.484**

PASS - Area of reinforcement provided is greater than area of reinforcement required

Deflection control - Section 7.4

Reference reinforcement ratio — $\rho_0 = \sqrt{(f_{ck} / 1 \text{ N/mm}^2)} / 1000$ = **0.006**

Required tension reinforcement ratio — $\rho = A_{sfM.req} / d$ = **0.002**

Required compression reinforcement ratio — $\rho' = A_{sfM.2.req} / d_2$ = **0.000**

Structural system factor - Table 7.4N — K_b = **1**

Reinforcement factor - exp.7.17 — $K_s = \min(500 \text{ N/mm}^2 / (f_{yk} \times A_{sfM.req} / A_{sfM.prov}), 1.5)$ = **1.5**

Limiting span to depth ratio - exp.7.16.a — $K_s \times K_b \times [11 + 1.5 \times \sqrt{(f_{ck} / 1 \text{ N/mm}^2)} \times \rho_0 / \rho + 3.2 \times \sqrt{(f_{ck} / 1 \text{ N/mm}^2)} \times (\rho_0 / \rho - 1)^{3/2}]$ = **200.6**

Actual span to depth ratio — h_{prop} / d = **13.3**

PASS - Span to depth ratio is less than deflection control limit

Crack control - Section 7.3

Limiting crack width — w_{max} = **0.3** mm

Variable load factor - EN1990 – Table A1.1 — ψ_2 = **0.6**

Serviceability bending moment — M_{sls} = **155.6** kNm/m

Tensile stress in reinforcement — $\sigma_s = M_{sls} / (A_{sfM.prov} \times z)$ = **140.9** N/mm^2

Load duration — Long term

Load duration factor — k_t = **0.4**

Effective area of concrete in tension — $A_{c.eff} = \min(2.5 \times (h - d), (h - x) / 3, h / 2)$ = **175000** mm^2/m

Mean value of concrete tensile strength — $f_{ct.eff} = f_{ctm}$ = **3.5** N/mm^2

Reinforcement ratio — $\rho_{p.eff} = A_{sfM.prov} / A_{c.eff}$ = **0.012**

Modular ratio — $\alpha_e = E_s / E_{cm}$ = **5.679**

Bond property coefficient — k_1 = **0.8**

Strain distribution coefficient — k_2 = **0.5**

k_3 = **3.4**

k_4 = **0.425**

Maximum crack spacing - exp.7.11 — $s_{r.max} = k_3 \times c_{sf} + k_1 \times k_2 \times k_4 \times \phi_{sfM} / \rho_{p.eff}$ = **420** mm

Maximum crack width - exp.7.8 — $w_k = s_{r.max} \times \max(\sigma_s - k_t \times (f_{ct.eff} / \rho_{p.eff}) \times (1 + \alpha_e \times \rho_{p.eff}), 0.6 \times \sigma_s) / E_s$

w_k = **0.178** mm

w_k / w_{max} = **0.592**

PASS - Maximum crack width is less than limiting crack width

Check stem design at base of stem

Depth of section $h = \mathbf{625}$ mm

Rectangular section in flexure - Section 6.1

Design bending moment combination 1 $M = \mathbf{491}$ kNm/m

Depth to tension reinforcement $d = h - c_{sr} - \phi_{sr} / 2 = \mathbf{559}$ mm

$K = M / (d^2 \times f_{ck}) = \mathbf{0.039}$

$K' = \mathbf{0.207}$

K' > K - No compression reinforcement is required

Lever arm $z = \min(0.5 + 0.5 \times (1 - 3.53 \times K)^{0.5}, 0.95) \times d = \mathbf{531}$ mm

Depth of neutral axis $x = 2.5 \times (d - z) = \mathbf{70}$ mm

Area of tension reinforcement required $A_{sr.req} = M / (f_{yd} \times z) = \mathbf{2127}$ mm²/m

Tension reinforcement provided 32 dia.bars @ 100 c/c

Area of tension reinforcement provided $A_{sr.prov} = \pi \times \phi_{sr}^2 / (4 \times s_{sr}) = \mathbf{8042}$ mm²/m

Minimum area of reinforcement - exp.9.1N $A_{sr.min} = \max(0.26 \times f_{ctm} / f_{yk}, 0.0013) \times d = \mathbf{1020}$ mm²/m

Maximum area of reinforcement - cl.9.2.1.1(3) $A_{sr.max} = 0.04 \times h = \mathbf{25000}$ mm²/m

$\max(A_{sr.req}, A_{sr.min}) / A_{sr.prov} = \mathbf{0.264}$

PASS - Area of reinforcement provided is greater than area of reinforcement required

Deflection control - Section 7.4

Reference reinforcement ratio $\rho_0 = \sqrt{(f_{ck} / 1\text{ N/mm}^2)} / 1000 = \mathbf{0.006}$

Required tension reinforcement ratio $\rho = A_{sr.req} / d = \mathbf{0.004}$

Required compression reinforcement ratio $\rho' = A_{sr.2.req} / d_2 = \mathbf{0.000}$

Structural system factor - Table 7.4N $K_b = \mathbf{1}$

Reinforcement factor - exp.7.17 $K_s = \min(500\text{ N/mm}^2 / (f_{yk} \times A_{sr.req} / A_{sr.prov}), 1.5) = \mathbf{1.5}$

Limiting span to depth ratio - exp.7.16.a $K_s \times K_b \times [11 + 1.5 \times \sqrt{(f_{ck} / 1\text{ N/mm}^2)} \times \rho_0 / \rho + 3.2 \times \sqrt{(f_{ck} / 1\text{ N/mm}^2)} \times (\rho_0 / \rho - 1)^{3/2}] = \mathbf{56.5}$

Actual span to depth ratio $h_{prop} / d = \mathbf{13.2}$

PASS - Span to depth ratio is less than deflection control limit

Crack control - Section 7.3

Limiting crack width $w_{max} = \mathbf{0.3}$ mm

Variable load factor - EN1990 – Table A1.1 $\psi_2 = \mathbf{0.6}$

Serviceability bending moment $M_{sls} = \mathbf{350.6}$ kNm/m

Tensile stress in reinforcement $\sigma_s = M_{sls} / (A_{sr.prov} \times z) = \mathbf{82.1}$ N/mm²

Load duration Long term

Load duration factor $k_t = \mathbf{0.4}$

Effective area of concrete in tension $A_{c.eff} = \min(2.5 \times (h - d), (h - x) / 3, h / 2) = \mathbf{165000}$ mm²/m

Mean value of concrete tensile strength $f_{ct.eff} = f_{ctm} = \mathbf{3.5}$ N/mm²

Reinforcement ratio $\rho_{p.eff} = A_{sr.prov} / A_{c.eff} = \mathbf{0.049}$

Modular ratio $\alpha_e = E_s / E_{cm} = \mathbf{5.679}$

Bond property coefficient $k_1 = \mathbf{0.8}$

Strain distribution coefficient $k_2 = \mathbf{0.5}$

$k_3 = \mathbf{3.4}$

$k_4 = \mathbf{0.425}$

Maximum crack spacing - exp.7.11 $s_{r.max} = k_3 \times c_{sr} + k_1 \times k_2 \times k_4 \times \phi_{sr} / \rho_{p.eff} = \mathbf{282}$ mm

Maximum crack width - exp.7.8 $w_k = s_{r.max} \times \max(\sigma_s - k_t \times (f_{ct.eff} / \rho_{p.eff}) \times (1 + \alpha_e \times \rho_{p.eff}), 0.6 \times \sigma_s) / E_s$

$w_k = \mathbf{0.069}$ mm

w_k / w_{max} = **0.231**

PASS - Maximum crack width is less than limiting crack width

Rectangular section in shear - Section 6.2

Design shear force — V = **398** kN/m

$C_{Rd,c} = 0.18 / \gamma_C$ = **0.120**

$k = \min(1 + \sqrt{(200 \text{ mm} / d)}, 2)$ = **1.598**

Longitudinal reinforcement ratio — $\rho_l = \min(A_{sr.prov} / d, 0.02)$ = **0.014**

$v_{min} = 0.035 \text{ N}^{1/2}/\text{mm} \times k^{3/2} \times f_{ck}^{0.5}$ = **0.447** N/mm²

Design shear resistance - exp.6.2a & 6.2b — $V_{Rd.c} = \max(C_{Rd.c} \times k \times (100 \text{ N}^2/\text{mm}^4 \times \rho_l \times f_{ck})^{1/3}, v_{min}) \times d$

$V_{Rd.c}$ = **413.9** kN/m

V / $V_{Rd.c}$ = **0.962**

PASS - Design shear resistance exceeds design shear force

Check stem design at prop

Depth of section — h = **625** mm

Rectangular section in shear - Section 6.2

Design shear force — V = **103** kN/m

$C_{Rd,c} = 0.18 / \gamma_C$ = **0.120**

$k = \min(1 + \sqrt{(200 \text{ mm} / d)}, 2)$ = **1.598**

Longitudinal reinforcement ratio — $\rho_l = \min(A_{sr1.prov} / d, 0.02)$ = **0.001**

$v_{min} = 0.035 \text{ N}^{1/2}/\text{mm} \times k^{3/2} \times f_{ck}^{0.5}$ = **0.447** N/mm²

Design shear resistance - exp.6.2a & 6.2b — $V_{Rd.c} = \max(C_{Rd.c} \times k \times (100 \text{ N}^2/\text{mm}^4 \times \rho_l \times f_{ck})^{1/3}, v_{min}) \times d$

$V_{Rd.c}$ = **250** kN/m

V / $V_{Rd.c}$ = **0.412**

PASS - Design shear resistance exceeds design shear force

Horizontal reinforcement parallel to face of stem - Section 9.6

Minimum area of reinforcement – cl.9.6.3(1) — $A_{sx.req} = \max(0.25 \times A_{sr.prov}, 0.001 \times t_{stem})$ = **2011** mm²/m

Maximum spacing of reinforcement – cl.9.6.3(2) — s_{sx_max} = **400** mm

Transverse reinforcement provided — 20 dia.bars @ 150 c/c

Area of transverse reinforcement provided — $A_{sx.prov} = \pi \times \phi_{sx}^2 / (4 \times s_{sx})$ = **2094** mm²/m

PASS - Area of reinforcement provided is greater than area of reinforcement required

Check base design at toe

Depth of section — h = **500** mm

Rectangular section in flexure - Section 6.1

Design bending moment combination 1 — M = **82.6** kNm/m

Depth to tension reinforcement — $d = h - c_{bb} - \phi_{bb} / 2$ = **417** mm

$K = M / (d^2 \times f_{ck})$ = **0.012**

K' = **0.207**

K' > K - No compression reinforcement is required

Lever arm — $z = \min(0.5 + 0.5 \times (1 - 3.53 \times K)^{0.5}, 0.95) \times d$ = **396** mm

Depth of neutral axis — $x = 2.5 \times (d – z)$ = **52** mm

Area of tension reinforcement required — $A_{bb.req} = M / (f_{yd} \times z)$ = **480** mm²/m

Tension reinforcement provided — 16 dia.bars @ 150 c/c

Area of tension reinforcement provided — $A_{bb.prov} = \pi \times \phi_{bb}^2 / (4 \times s_{bb})$ = **1340** mm²/m

Minimum area of reinforcement - exp.9.1N — $A_{bb.min} = \max(0.26 \times f_{ctm} / f_{yk}, 0.0013) \times d$ = **761** mm²/m

Maximum area of reinforcement - cl.9.2.1.1(3) — $A_{bb.max} = 0.04 \times h$ = **20000** mm²/m

$\max(A_{bb.req}, A_{bb.min}) / A_{bb.prov}$ = **0.568**

PASS - Area of reinforcement provided is greater than area of reinforcement required

Crack control - Section 7.3

Limiting crack width	w_{max} = **0.3** mm
Variable load factor - EN1990 – Table A1.1	ψ_2 = **0.6**
Serviceability bending moment	M_{sls} = **61.2** kNm/m
Tensile stress in reinforcement	$\sigma_s = M_{sls} / (A_{bb.prov} \times z)$ = **115.3** N/mm^2
Load duration	Long term
Load duration factor	k_t = **0.4**
Effective area of concrete in tension	$A_{c.eff} = \min(2.5 \times (h - d), (h - x) / 3, h / 2)$ = **149292** mm^2/m
Mean value of concrete tensile strength	$f_{ct.eff} = f_{ctm}$ = **3.5** N/mm^2
Reinforcement ratio	$\rho_{p.eff} = A_{bb.prov} / A_{c.eff}$ = **0.009**
Modular ratio	$\alpha_e = E_s / E_{cm}$ = **5.679**
Bond property coefficient	k_1 = **0.8**
Strain distribution coefficient	k_2 = **0.5**
	k_3 = **3.4**
	k_4 = **0.425**
Maximum crack spacing - exp.7.11	$s_{r.max} = k_3 \times c_{bb} + k_1 \times k_2 \times k_4 \times \phi_{bb} / \rho_{p.eff}$ = **558** mm
Maximum crack width - exp.7.8	$w_k = s_{r.max} \times \max(\sigma_s - k_t \times (f_{ct.eff} / \rho_{p.eff}) \times (1 + \alpha_e \times \rho_{p.eff}), 0.6 \times \sigma_s) / E_s$
	w_k = **0.193** mm
	w_k / w_{max} = **0.643**

PASS - Maximum crack width is less than limiting crack width

Rectangular section in shear - Section 6.2

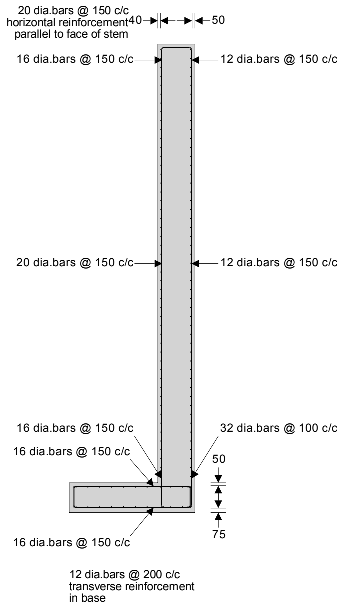
Design shear force	V = **110.2** kN/m
	$C_{Rd,c} = 0.18 / \gamma_C$ = **0.120**
	$k = \min(1 + \sqrt{(200\text{ mm} / d)}, 2)$ = **1.693**
Longitudinal reinforcement ratio	$\rho_l = \min(A_{bb.prov} / d, 0.02)$ = **0.003**
	$v_{min} = 0.035\text{ N}^{1/2}/\text{mm} \times k^{3/2} \times f_{ck}^{0.5}$ = **0.487** N/mm^2
Design shear resistance - exp.6.2a & 6.2b	$V_{Rd.c} = \max(C_{Rd.c} \times k \times (100\text{ N}^2/\text{mm}^4 \times \rho_l \times f_{ck})^{1/3}, v_{min}) \times d$
	$V_{Rd.c}$ = **203.3** kN/m
	$V / V_{Rd.c}$ = **0.542**

PASS - Design shear resistance exceeds design shear force

Secondary transverse reinforcement to base - Section 9.3

Minimum area of reinforcement – cl.9.3.1.1(2)	$A_{bx.req} = 0.2 \times A_{bb.prov}$ = **268** mm^2/m
Maximum spacing of reinforcement – cl.9.3.1.1(3)	s_{bx_max} = **450** mm
Transverse reinforcement provided	12 dia.bars @ 200 c/c
Area of transverse reinforcement provided	$A_{bx.prov} = \pi \times \phi_{bx}^2 / (4 \times s_{bx})$ = **565** mm^2/m

PASS - Area of reinforcement provided is greater than area of reinforcement required



Reinforcement details