Group 6

ARUP
FSGEC

THE
FANTASTIC
STRUCTURAL
AND
GEOTECHNICAL
ENGINEERS
CONSULTANCY

Isabella LONG, Bihi MOHAMED, Max OSTROVERHY, Ciying WANG, Emily WANG, Hanaa YAKOUB

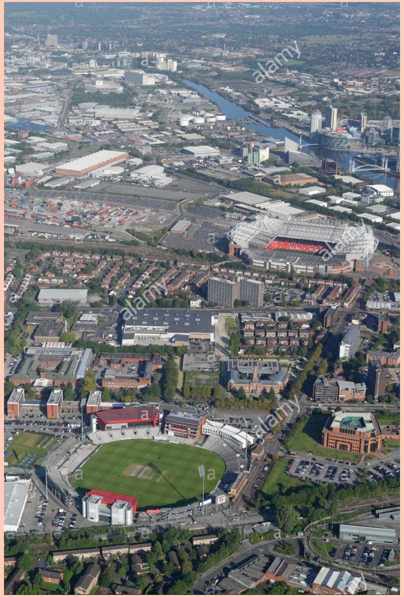
Brief Details

Location: 53,4656, 02.2986 Manchester

Soil: Dense Clay

Building type: Residential: 10 storey with 1 storey basement

Old Trafford area- residential, stadium, River Irwell



Design loads for the structure:: Imposed wind load

For facades a and b wall dimensions 42 * 35.5m

- Windward 0.91 (kN/m^2)
- leeward 0.57 (kN/m^2)

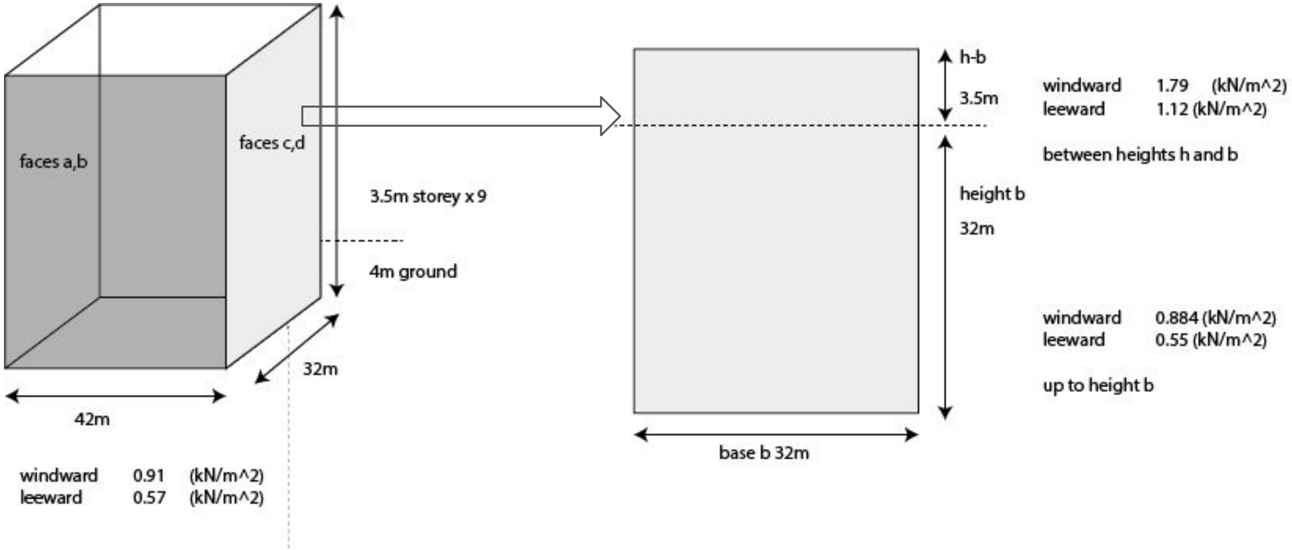
For facades c and d wall dimensions 32 * 35.5m

- Windward 0.89 (kN/m^2)
- Leeward 0.55 (kN/m^2)

up to height b

- Windward 1.79 (kN/m^2)
- Leeward 1.12 (kN/m^2)

between heights h and b



Design loads for the structure: imposed, snow load

$$s = \mu_i C_e C_t s_k$$

Assumptions & Values from Eurocode 1:

- **Flat roof** - snow load shape coefficient $\mu_i = 0.8$
- **Surrounding is an urban landscape of normal topography** - exposure coefficient $C_e = 1.0$
- **Roof does not have high thermal transmittance** - $C_t = 1$
- **Altitude A** - 30m
- **Zone number** Z - 3
- **Building is located in the UK** - Snow load relationship $s_k = 0{,}140Z - 0{,}1 + \frac{A}{501}$

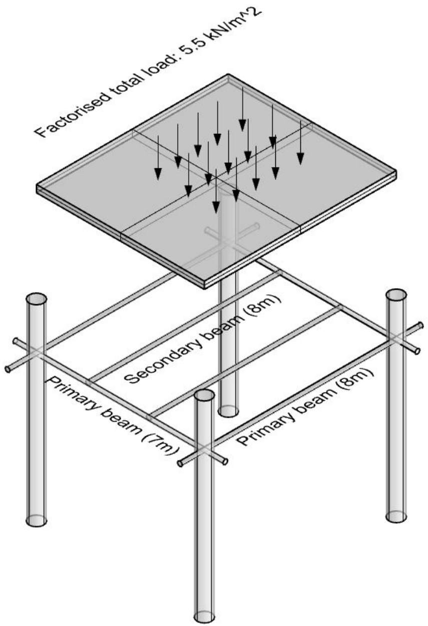
$$s = 0.304\ kN/m^2$$

The configuration of the structural elements for beams, and floors slabs

Parameters	Values
total load	3.7
MEP	0.1
tiles	0.3
ceiling	0.1
composite slab	3.2
occupancy	2
moveable partitions	1.2
F.S dead	1.35
F.S live	1.5
total load+ F.S.	5.475 (kN/m^2)

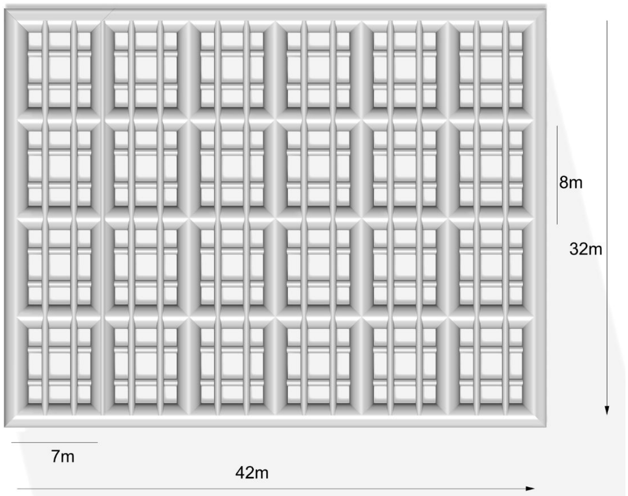
load used from table	5.5	(kN/m^2)
max span	3.65	m
secondary beams	2	
new span (x)	2.5	
new span (y)	2.67	
slab selected:	10	cm, concrete
	0.7	mm, steel
slab weight	190	(kg/m^29
total slab load	2.362	kN/m^2
total floor area	13440	
total slab load	31745.28	kN

wall dimensions	ground	32	42	4
	other 9 floors	32	42	3.5
brick dimensions	16	15	30	cm
brick mass	2.05	kg		
building wall area	ground	592	m^2	
	other 9 floors	4662	m^3	
dead load on perimeter beam	ground	5.29	kN/m	
	other 9 floors	41.63	kN/m	
load	3.7	(kN/m^2)		
slab dead load	2.4	(kN/m^2)		
slab area	56	m^2		
total load for each bay	341.6	kN		
total load on each beam	170.8	kN		



Beam iteration 1

Deflections:			
E steel	210000000		
I	1/200		
2 Point loads	x (7m)	0.00000113	m^4
	y (8m)	**0.000217**	m^4
Uniformly distributed load	x 170.8kN/ 7m/ = 24.4kN/m	0.000104	m^4
	y 170.8kN/8m= 21.35kN/m	0.000136	m^4
worst case	0.000217	m^4	
	21688.9	cm^4	
IPE beam selected	IPE400		
Weight	66.3	kg/m	
	0.64974	kN/m	

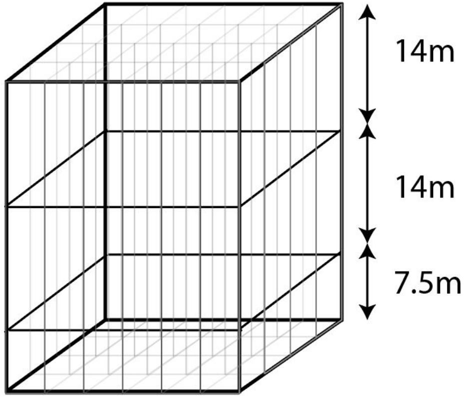


Plan view of primary and secondary beams

total beam length	primary	434m
	secondary	720m
	Total	1154m
total beam load per floor	749.79996	kN
total beam load for building	7497.9996	kN

Columns Iteration 1

Levels	Live Loads(kN)	Deadloads (kN)	Total (kN)	Cumulative (kN)
Roof	408.56	6306.22	6714.72	6714.72
7	2688	6306.22	8994.22	42691.60
3	2688	6306.22	8994.22	78668.48
1	2688	3617.06	6305.06	93967.76



Type	Levels	Load (kN)	Load taken by each Bay (kN)	Load taken by edge columns (kN)	Load taken by central columns (kN)	Tallest floor (m)
A	7-10	30711.417	1279.64	**1535.574**	1279.64	3.5
B	3-6	57104.14	2379.34	**2855.21**	2379.334	3.5
C	Basement, 1-2	70398.84	2933.28	**3519.94**	2933.28	4

Column Profile	Design Axial Force resistance	load (kN/m)	number of floors	total height (m)	total length of columns per floor (m)	column load per floor (kN)
UC 203x203x60	2390	0.588	4	14	490	288.12
UC 254x254x107	4360	1.0486	4	14	490	513.81
UC 254x254x132	5260	1.2936	2	7.5	262.5	339.57
						1141.50

Combination of actions

Combination of actions: ULS		PERMANENT		VARIABLE													
		dead loads		live load (building)			live load (roof)			snow load			wind load				
Combination	**Load type**	gammaG	sumG	gammaQb	psi0b	bQ	ammaQ	psi0r	rQ	gammaQs	psi0s	sQ	gammaQw	psi0w	wQ	**RESULTS**	
1	**live load (building and roof)**	1.35	2.362	1.5	1	2	1.5	1								6.1887	
2	**live load (building)**	1.35	2.362	1.5	1	2				1.5	0.5	0.30394	1.5	0.6		6.416655	
3	**snow load**	1.35	2.362	1.5	0.7	2				1.5	1	0.30394	1.5	0.6		5.74461	
4	**wind load**	1.35	2.362	1.5	0.7	2				1.5	0.5	0.30394	1.5	1		5.516655	
																6.416655	Worst case
																kN/m2	Unit

Combination of actions: SLS		PERMANENT		VARIABLE													
		dead loads		live load (building)			live load (roof)			snow load			wind load				
Combination	**Load type**	gammaG	sumG	gammaQb	psi0b	bQ	ammaQ	psi0r	rQ	gammaQs	psi0s	sQ	gammaQw	psi0w	wQ	**RESULTS**	
1	**live load (building and roof)**	1	2.362	1	1	2	1	1								4.362	
2	**live load (building)**	1	2.362	1	1	2				1	0.5	0.30394	1	0.6		4.51397	
3	**snow load**	1	2.362	1	0.7	2				1	1	0.30394	1	0.6		4.06594	
4	**wind load**	1	2.362	1	0.7	2				1	0.5	0.30394	1	1		3.91397	
																4.51397	Worst case
																kN/m2	Unit

* psi factor: from EC0 Table A1.1
* gama (safety factor): from EC0 Table A2.4
* combination equation: EC0 Eq. 6.10
* assume no live loads on roof
* The loads calculated are only vertical, so no wind loads on slabs & beams

First iteration Checks for the ULS and SLS of Columns

ULS Check on column

Initial geometry	Section	A (m^2)	fy (kPa)	Nc,Rd(kN)	Ned(kN)	Compression	<1
column 7-10	UC 203 x 203 x 60	0.00764	355000	2.71E+03	3254.470892	1.20E+00	no
column 3-6	UC 254x254x107	0.0136	355000	4.83E+03	5909.669105	1.22E+00	no
column 1-2	UC 254x254x132	0.0168	355000	5.96E+03	7031.607795	1.18E+00	no

Initial geometry	Section	L(m)	Wpl,y(m^3)	Wpl,z(m^3)	γ_M0	My,Rd(kNm)	Mz,Rd(kNm)
column 7-10	UC 203 x 203 x 60	3.5	0.0006561	0.0003053	1	232.9155	108.3815
column 3-6	UC 254x254x107	3.5	0.001484	0.000697	1	526.82	247.435
column 1-2	UC 254x254x132	4	0.001869	0.0008784	1	663.495	311.832
		load_y(kN)	load_z(kN)	My,Ed(kNm)	Mz,Ed(kNm)	Ratio	<1
		3249.81	3249.81	5687.1675	5687.1675	7.81E+01	no
		5901.27	5901.27	10327.2225	10327.2225	6.26E+01	no

Initial geometry	Section	L(m)	E (kPa)	I(m^4)	Ncr(kN)	λ̄	α	
column 7-10	UC 203 x 203 x 60	3.5	210000000	0.00002065	3493.839958	0.8810678457	0.49	
column 3-6	UC 254x254x107	3.5	210000000	0.00005931	10034.84978	0.6936305184	0.49	
column 1-2	UC 254x254x132	4	210000000	0.00007535	9760.730328	0.7816775883	0.49	
		γ_M1	ø	X	Nb,Rd	Ned(kN)	Bucking	<1
		1	1.055001897	6.12E-01	1.66E+03	3254.470892	1.96E+00	no
		1	0.861501125	7.29E-01	3.52E+03	5909.669105	1.68E+00	no
		1	0.9480209351	6.74E-01	4.02E+03	7031.607795	1.75E+00	no

SLS Check on column

Initial geometry	Section	storey height(m)	deflection allowance(m)	w (kN/m)	I (cm4)	Max horizontal deflection (m)	allowed?
column 7-10	UC 203 x 203 x 60	3.5	0.01166666667	54.59	11335	0.9430	no
column 3-6	UC 254x254x107	3.5	0.01166666667	54.59	22765	0.4696	no
column 1-2	UC 254x254x132	4	0.01333333333	54.59	30234	0.0431	no

Vertical load calculation with braces

Load type	magnitude (kN/m)	Applied member(s)	Beam length	Total load (kN)	Total vertical load (kN)
dead	9.448	interior beams (+roof)	6220	58766.56	119871.9
live	8	interior beams (-roof)	5598	44784	
snow	1.21576	interior beams (only roof)	622	756.2027	
dead + dead (perimeter)	9.4017	exterior beams x (-roof)	756	7107.685	
dead (perimeter)	4.724	exterior beams x (only roof)	84	396.816	
dead + dead (perimeter)	9.4017	exterior beams y (-roof)	576	5415.379	
live	4	exterior beams y (-roof)	576	2304	
snow	0.60788	exterior beams y (only roof)	64	38.90432	
dead	4.724	exterior beams y (only roof)	64	302.336	

Load experienced on foundations not considering the factors of safety.

Geotechnical background

Soil parameters

Undrained Shear strength Cu (kPa)	**c' , cohesion (kPa)**	**E' Youngs Modulus (MPa)**	**ϕ , Friction angle (°)**	**S_u Shear strength**	**Soil material**
200	5	40	24	200	Dense Clay
Unsaturated unit weight above water level (kg/m)	**Saturated unit weight below water level (kg/m)**	**Water level below ground (meters)**			
17.5	19	11			

The water level is at 11 meter as sourced from the nearest water borehole where water struck at 11 meters depth, although the resting water level is at 14.8 meter one averaged with a unsaturated unit weight of 19 and saturated unit weight of 17.5. [i]

[i] Blair drilling. (2020). *Borehole record form.* Available: http://scans.bgs.ac.uk/sobi_scans/boreholes/20862786/images/20862778.html. Last accessed 02/04/2021. SK22 2NS BGS ID: 20862786 : BGS Reference: SK08NW63

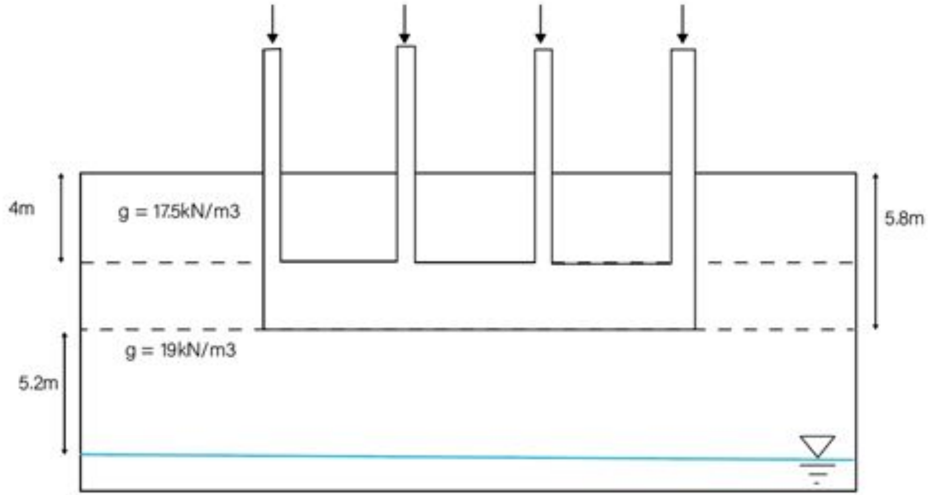
Initial design approach

Table 7.1 Choice of foundation

	Typical solution	Alternative solution
First choice	Pad or strip foundations	–
Second choice	Pad or strip foundations associated with ground improvement	Raft with/without ground improvement
Third choice	Piled foundation	Piled raft foundation

The Institution of Structural Engineers Manual for the geotechnical design of structures to Eurocode 7 117

The initial geotechnical approach was to begin with a raft design as recommended by EC7 Table 7.1, whereby it is better to use pile design as the raft will be be very thick.



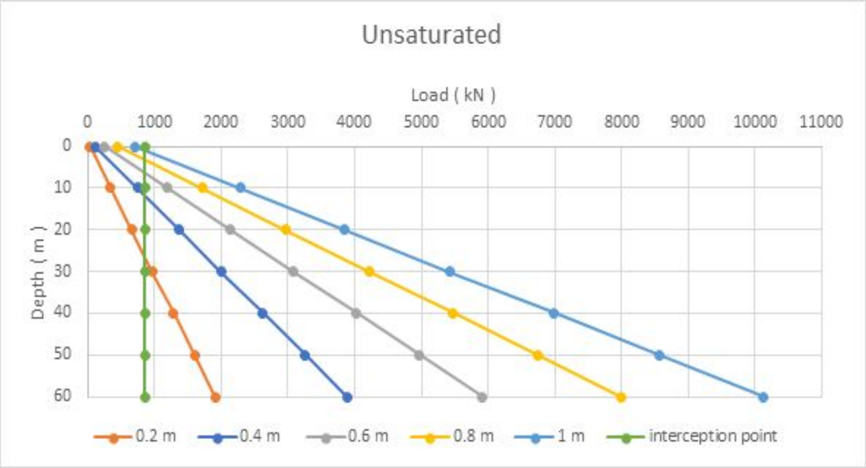
Thickness (m)	W_f	σ_{vo}' (kPa)	q' (kPa)
1	32256	87.5	-25.32161057
1.4	45158.4	94.5	-22.72161057
1.8	58060.8	101.5	-20.12161057
2.2	70963.2	108.5	-17.52161057
2.6	83865.6	115.5	-14.92161057
3	96768	122.5	-12.32161057
3.4	109670	129.5	-9.721610565
3.8	122573	136.5	-7.121610565
4.2	135475	143.5	-4.521610565
4.6	148378	150.5	-1.921610565
5	161280	157.5	0.678389435

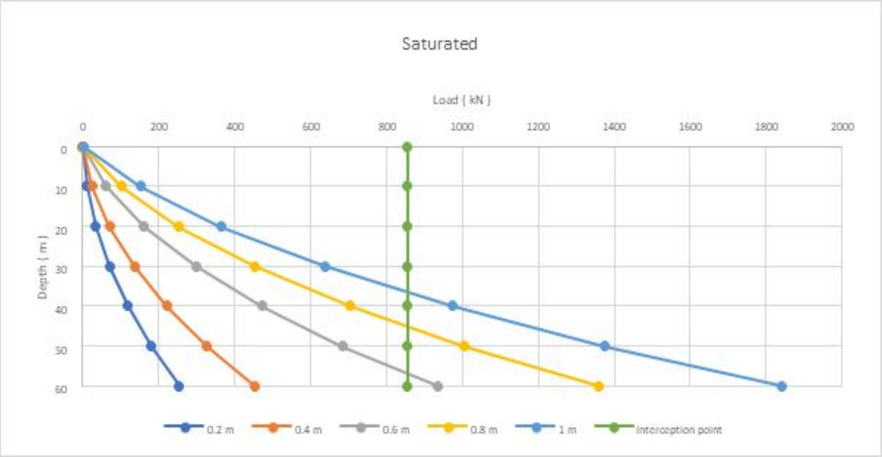
ULS Pile Design

The pile design parameters can calculated by comparing the incident load on the piles and the shaft friction and end bearing capacity load by 4. The load Q applied on individual piles can be plot in order choose a pile diameter and depth at which the pile can resist incident loads.

$$Q \leq \frac{Q_b + Q_s}{4F}, Q \leq \frac{4.5\pi D^3 + 30\pi D^2 z + 0.8\pi D z^2}{4F}$$

$$Q \leq \frac{Q_b + Q_s}{4F}, Q \leq \frac{1800\pi D^2 + 400\pi D z}{4F}$$

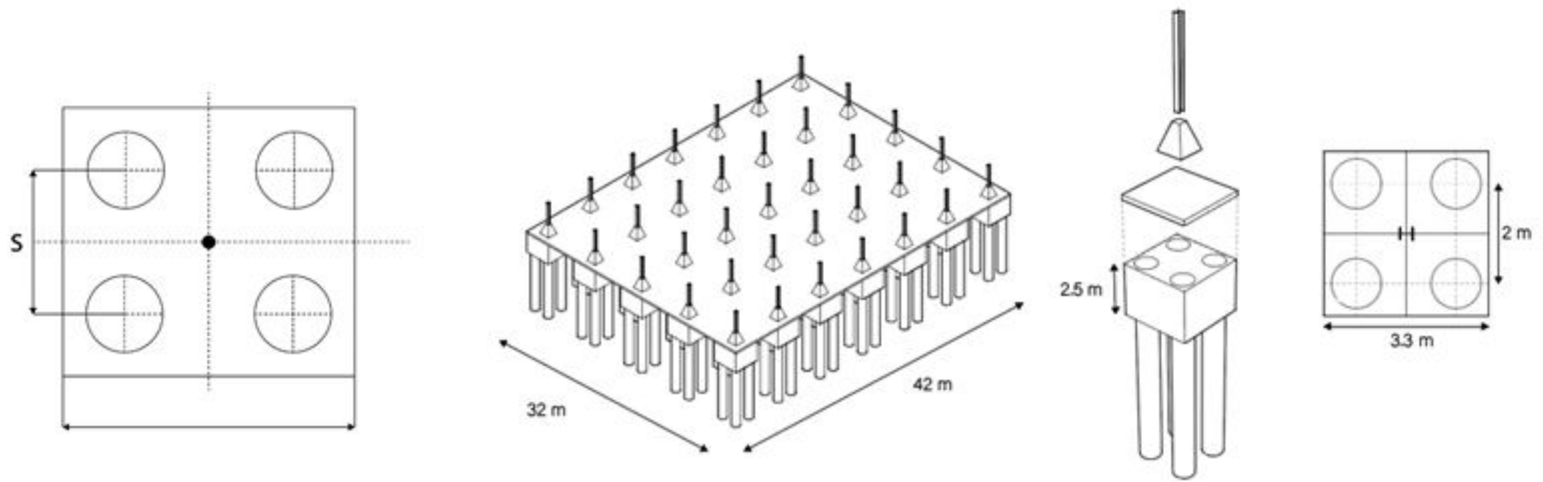




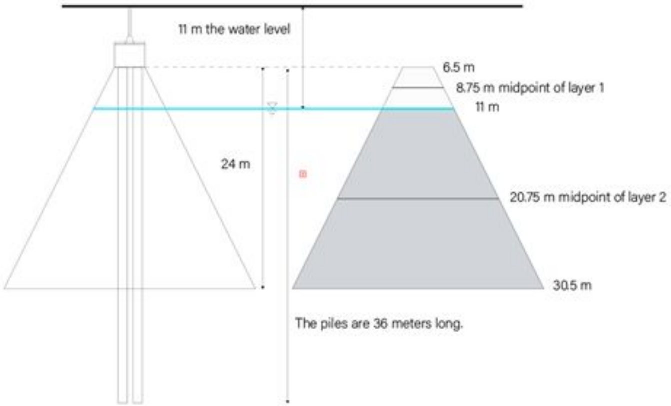
Pile cap Design

Steel sheet between connection and ramped connection allowing for transition of material properties and load transfer. For the pile cap dimensions we can use a recommended guide for the dimensions and thickness.

Whereby the S is spacing and α= 2-3 and is spacing factor of piles, it depends on ground conditions with the pileØ being the diameter of of the piles.



SLS Check - Settlements



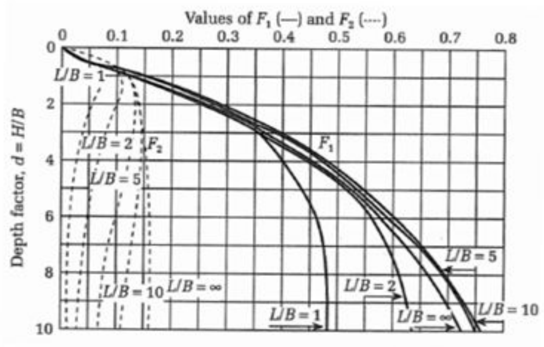
Assumption: 1 stratum, deep homogenous clay layer whereby the D, is ⅔ D of 24 meters.

Immediate settlement

$$I_\rho = F_1 + F_2 \frac{(1-2v)}{(1-v)} = 0.48 + 0.02 \frac{(1-2(0.3))}{(1-0.3)} = 0.49142857 \approx 0.49$$

$$\rho = qB\frac{(1-v^2)}{E} I_\rho = (856.2277 * 4/3.3^2) * 3.3 * \frac{(1-0.3^2)}{40 * 10^3} * (0.49) = 11.6\text{mm}$$

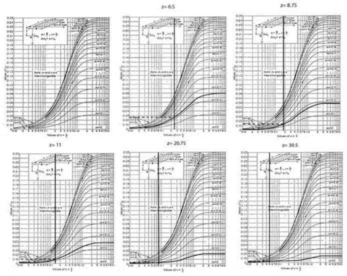
B	q	F_2	F_1	I_ρ	ρ_i
3.3	314.5005326	0.02	0.48	0.491429	0.0116

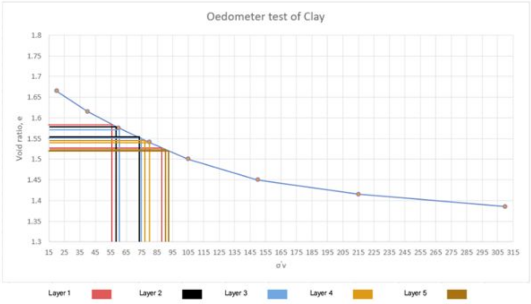


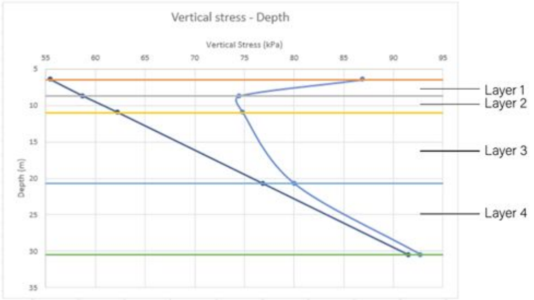
SLS Check - settlement

Consolidation settlement

Assumptions : for oedometer test, We can calculate the consolidation settlement based on the ratio changes of stress in soil layer and void ratio's , we can source this by using a oedometer test similar to clay at site. The sourced clay as has a E_u/C_u of 200 and our clay as a E_u/C_u of 300 hence within the same group in terms of a similar PI greater than 50.







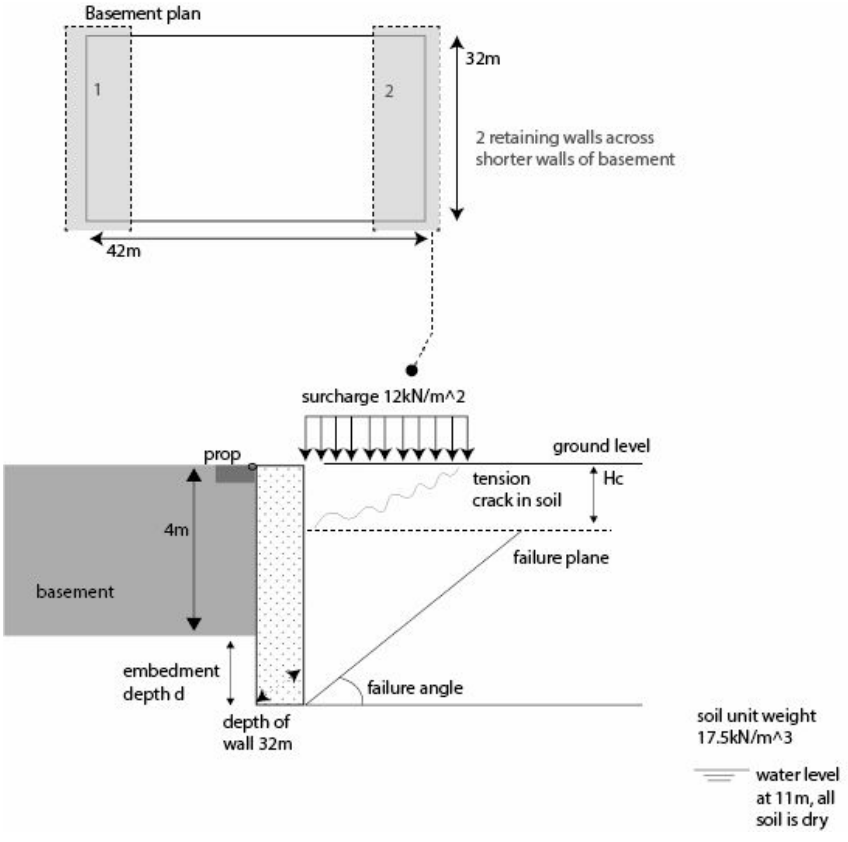
Depth	Initial e_0	Final e_f	Δ e	$\Delta\sigma_v'$	M_v
6.5	1.58	1.525	0.055	31.45	0.000677832
8.75	1.575	1.552	0.023	15.725	0.000568015
11	1.57	1.55	0.02	12.58	0.000618609
20.75	1.54	1.536	0.004	3.145	0.000500732
30.5	1.525	1.524	0.001	1.258	0.000314817

Depth	Average stress	mv	Consolidation Settlement	Total settlement
6.5	71.225	0.00067783	0.31381099	2.81097765
8.75	66.6125	0.00056802	0.331072978	
11	68.54	0.00061861	0.466394066	
20.75	78.4475	0.00050073	0.815084874	
30.5	92.129	0.00031482	0.884614743	

Room for error with great uncertainties at times.

$$\rho_{Total} = \rho_{immidieate} + \rho_{consoldiation} = 0.0116 + 2.8110 = 2.8226 \text{ meters}$$

Retaining Wall design



Initial assumptions:

- Dense clay is cohesive, so will fail with a tension crack
- Clay is dry as the water level is deep at 11m, and unit weight is 17.5kN/m^3
- Unit weight of concrete wall is 24kN/m^3
- Surcharge is an unfavourable action when considering the toppling or overturning moment checks
- Surcharge of 12kPa accounting for vehicles

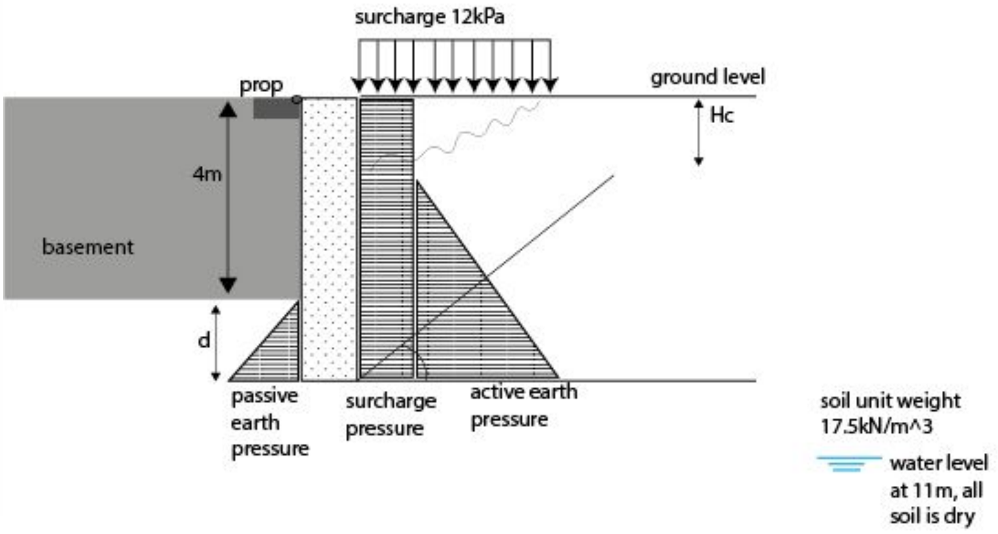


Table 2: input parameters

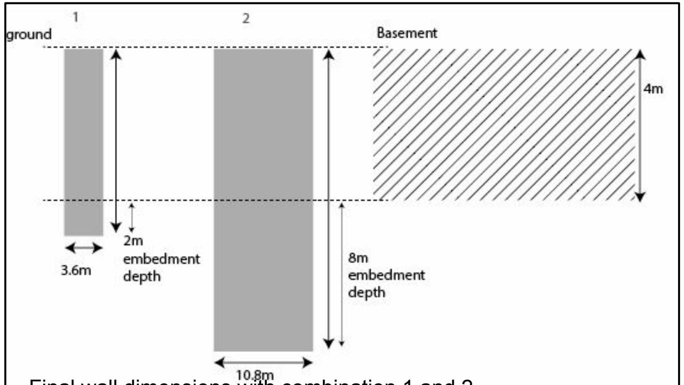
Parameter	Value	Units	
angle Φ'	24	degrees	
γ factor 1.25	19.6	degrees	
cohesion c'	5	kPa	
γ factor 1.25	4	kPa	
unit weight	17.5	kNm^3	
Active		Passive	
Ka	0.421	Kp	2.37
	0.497		2.01
Hc	0.880	m	
	0.648	m	

Table 3: Partial factors

Friction angle	ϒΦ'	1 1.25	M1 M2	DA1-1	DA1-2
Cohesion	ϒ c'	1 1.25	M1 M2	A1+M1	A2+M2
Permanent loads	ϒG	1.35 1	A1 A2	Earth pressures, wall weight	
Variable loads	ϒQ	1.5 1.3	A1 A2	surcharge	

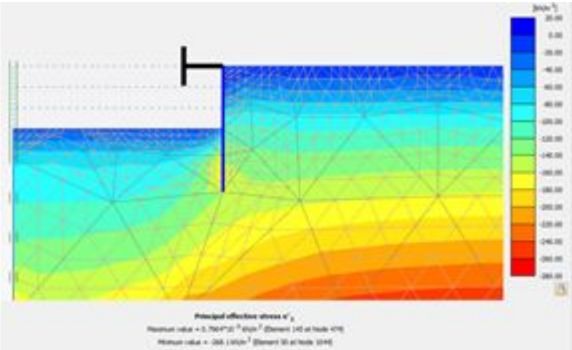
Table 4: Moments checks

Moments											
destabilising	Factive (kN/m)	Distance (m)	ϒG	Moment (kNm/m)	F surcharge (kN/m)	Distance (m)	ϒQ	Moment (kNm/m)	Total Moment (kNm/m)		
comb. 1	117.9	1.7	1.35	271.6	30.4	3	1.5	136.6	408.3		
comb. 2	1325.5	3.8	1.35	6770.9	71.79	6	1.5	644.9	7415.9		
stabilising	Fpassive (kN/m)	Distance (m)	ϒG	Moment(kNm/m)	Fprop (kN/m)	Distance (m)	ϒG	Moment (kNm/m)	Fwall (kN/m)	ϒG	Total moment (kNm/m)
comb. 1	113.8	0.67	1	75.9	34.5	6	1	206.9	72	1	282.7
comb. 2	1216.1	2.67	1	3242.9	181.03	12	1	2172.4	144	1	5415.3
SLS check	Total Moment (kNm/m)	Total moment (kNm/m)									
comb. 1	408.3	282.7+72w^2									
comb. 2	7415.9	5415.3+144w^2									
Factor of safety 3			width of wall:								
comb. 1	1224.9	13.1	3.6m								
comb. 2	22247.6	116.9	10.8m								

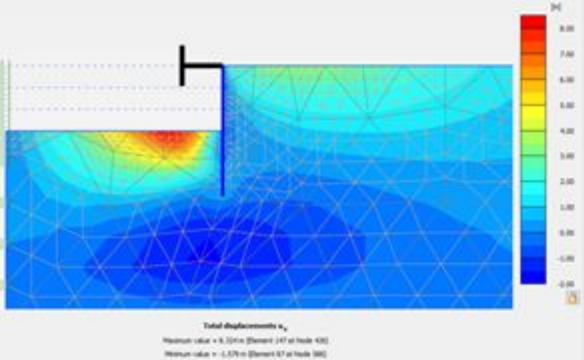


Final wall dimensions with combination 1 and 2

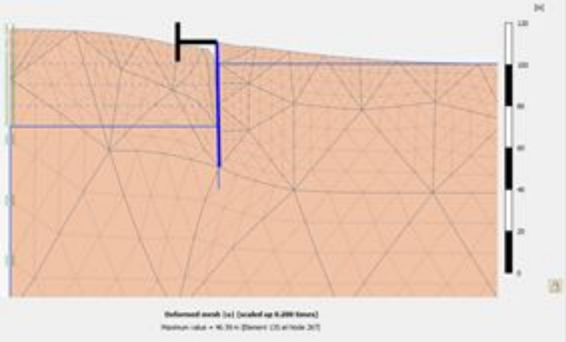
Retaining wall based on the finite element model in Plaxis



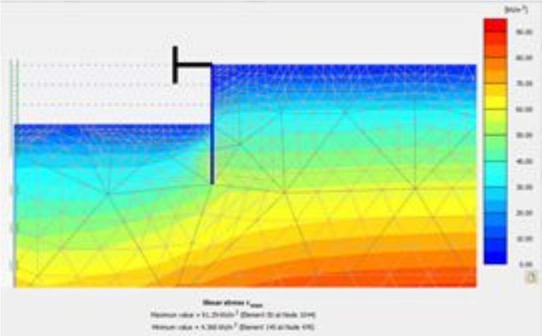
Principal effective stress at final stage



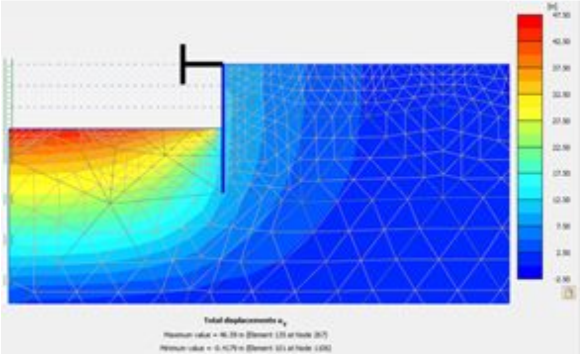
Total x displacement at final stage



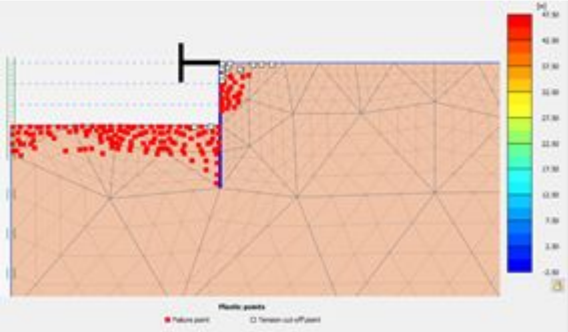
Deformed mesh at final stage



Maximum shear stress at final stage



Total y displacement at final stage

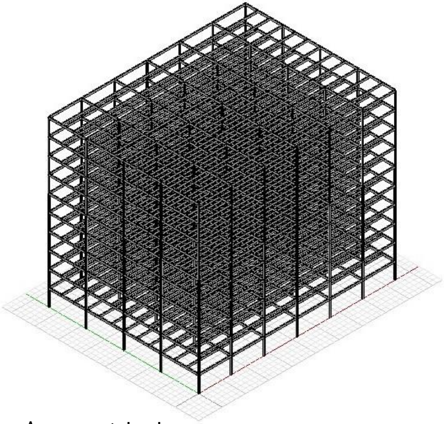


Plastic points at final stage, showing shear failure plane

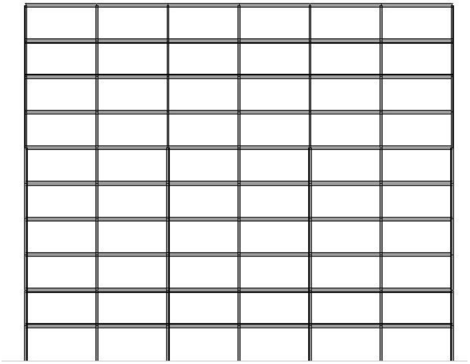
Design of the structural elements GSA

Iteration 1	material	type	section
column 1-2	S355 steel	UC	254x254x132
column 3-6	S355 steel	UC	254x254x107
column 7-10	S355 steel	UC	203x203x60
beam x	S355 steel	IPE	IPE 400
beam y	S355 steel	IPE	IPE 400
secondary beams	S355 steel	IPE	IPE 400

Iteration 2,3,4 and 5	material	type	section
column 1-2	S355 steel	UC	254x254x167
column 3-6	S355 steel	UC	254x254x132
column 7-10	S355 steel	UC	203x203x86
beam x	S355 steel	IPE	IPE 400
beam y	S355 steel	IPE	IPE 400
secondary beams	S355 steel	IPE	IPE 400
circular braces	S355 steel	circular	diameter=323.9,wall=12.5

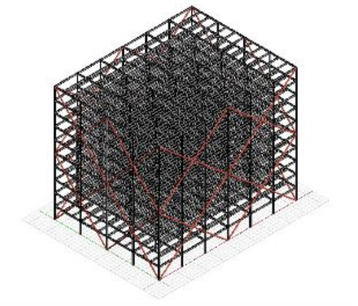


Axonometric view



Section view

ULS & SLS of optimised structural components



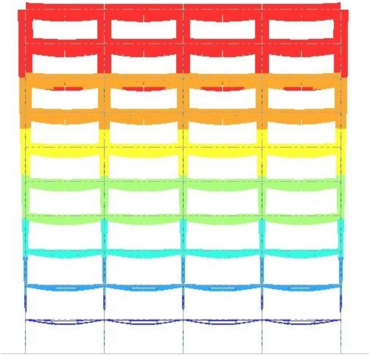
Element	Check	Side	A (cm^2)	b (mm)	tf (mm)	tw (mm)	r (mm)	Av (mm^2)	fy (MPa)	V_c,Rd (kN)	V_Ed (kN)	ratio	<1?
Beams	ULS - shearing	7m side	84.46	180	13.5	8.6	21	4269.1	355	874.99	27.34	0.03	yes
		8m side									31.25	0.04	yes
	ULS- bending							W_pl(cm^3)	fy (MPa)	M_c,Rd	M_Ed	ratio	<1?
		7m side						1307	355	463.985	47.85	0.10	yes
		8m side									62.49	0.13	yes
	ULS- bending + shear	V_Ed/ V_c,Rd <0.5, effect neglected											
	SLS - vertical deflection			w (kN/m)	E (MPa)	I (cm4)		max vertical deflection (m)			Allowed deflection (span/200)		allowed?
		7m side		5.50	210000	23128		0.0035			0.035		yes
		8m side		5.50	210000	23128		0.0060			0.04		yes

Element	Check	Section	E (kPa)	I	fy (kPa)	A (m^2)	Ncr (z-z)	h/b	buckling	Lamda	imperfect	φ	X	N_b,Rd	N_Ed (kN)	ratio	<1?
Columns	ULS - buckling	UC 203 x 203 x 100	210000000	0.0000206	355000	0.00764	3493.83995	1.018	c	0.881	0.49	1.06	0.61	1658.53	3266.36	1.97	no
		UC 254x254x132	210000000	0.0000593	355000	0.0136	10034.8497	1.031	c	0.694	0.49	0.86	0.73	3517.82	5969.99	1.70	no
		UC 254x254x167	210000000	0.0000753	355000	0.0168	12748.709	1.057	c	0.684	0.49	0.85	0.73	4381.08	7142.97	1.63	no
	ULS - compression											A (m^2)	fy (kPa)	N_c,Rd (kN	N_Ed (kN)	ratio	<1?
		UC 203 x 203 x 100										0.00764	355000	2712.2	3266.36	1.20	no
		UC 254x254x132										0.0136	355000	4828	5969.99	1.24	no
		UC 254x254x167										0.0168	355000	5964	7142.97	1.20	no
	SLS - horizontal deflection							w (kN/m)	E (MPa)	I (cm4)		max vertical deflection (m)			Allowed deflection (height/300)		allowed?
		UC 203 x 203 x 100						54.59	210000	11335		1.1472			0.0117		no
		UC 254x254x132						54.59	210000	22765		0.5712			0.0117		no
		UC 254x254x167						54.59	210000	30234		0.0459			0.0133		no

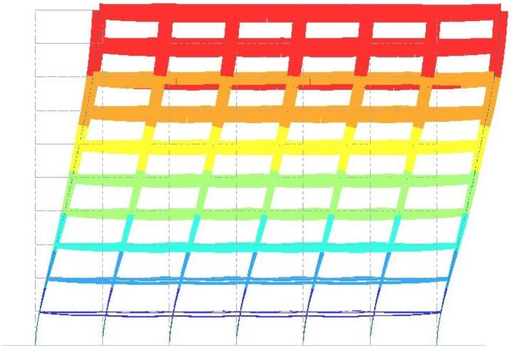
For the braced frame system, the following checks can be made:

1. Frame deflection: unit load method (Datoo, 2015)
2. Frame stability: any frame structure should be examined for susceptibility to sway instability into second order effect. (Eng, 2009)
3. Software simulation: revit, GSA

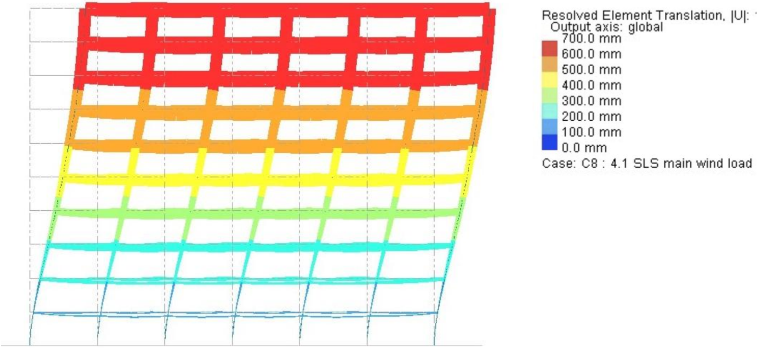
Iterations and adjustments



Y side section view SLS wind deformation

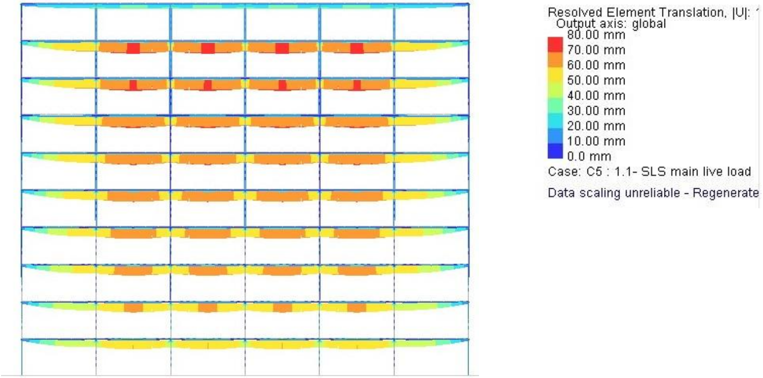


X side section view SLS wind deformation



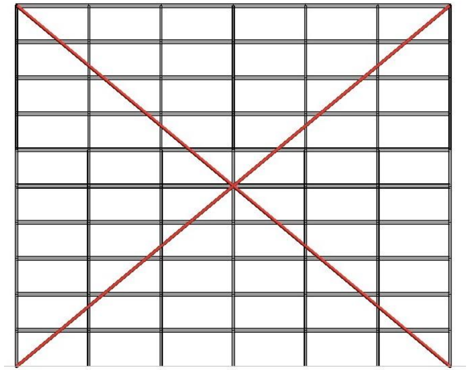
X side section view SLS wind deformation with new columns

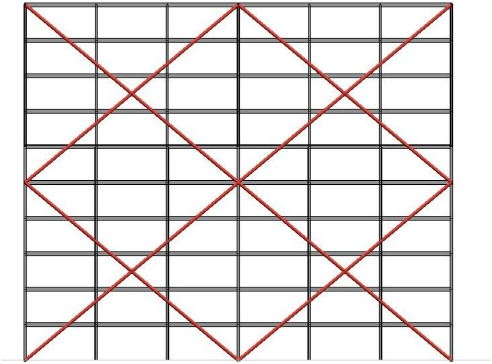
- The main problem is lateral drift
- We need braces
- Live load deformation is not the most important

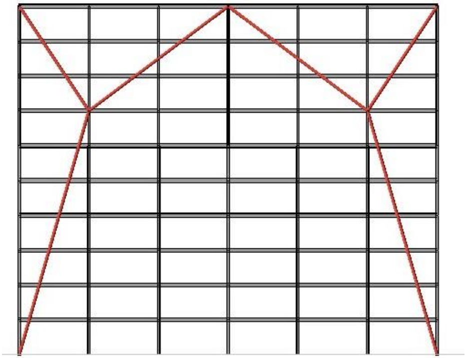


Live load deformation

Braces



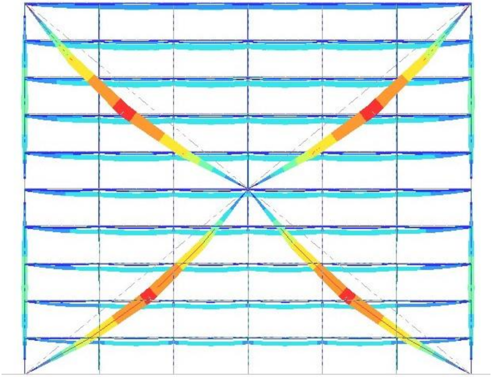


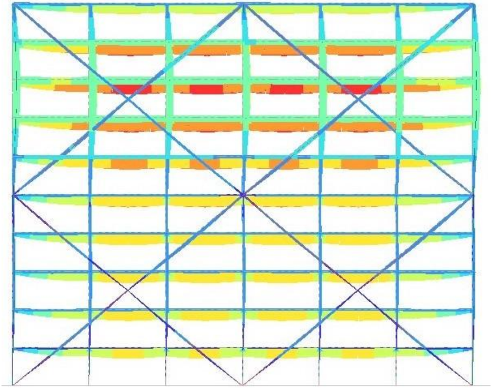


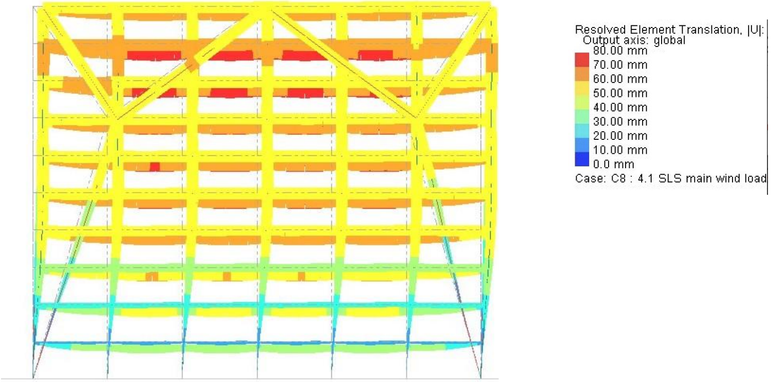
Iteration 3, big X braces on all side

Iteration 4, 4 X braces on all sides

Iteration 5, symmetrical portal bracing on all sides

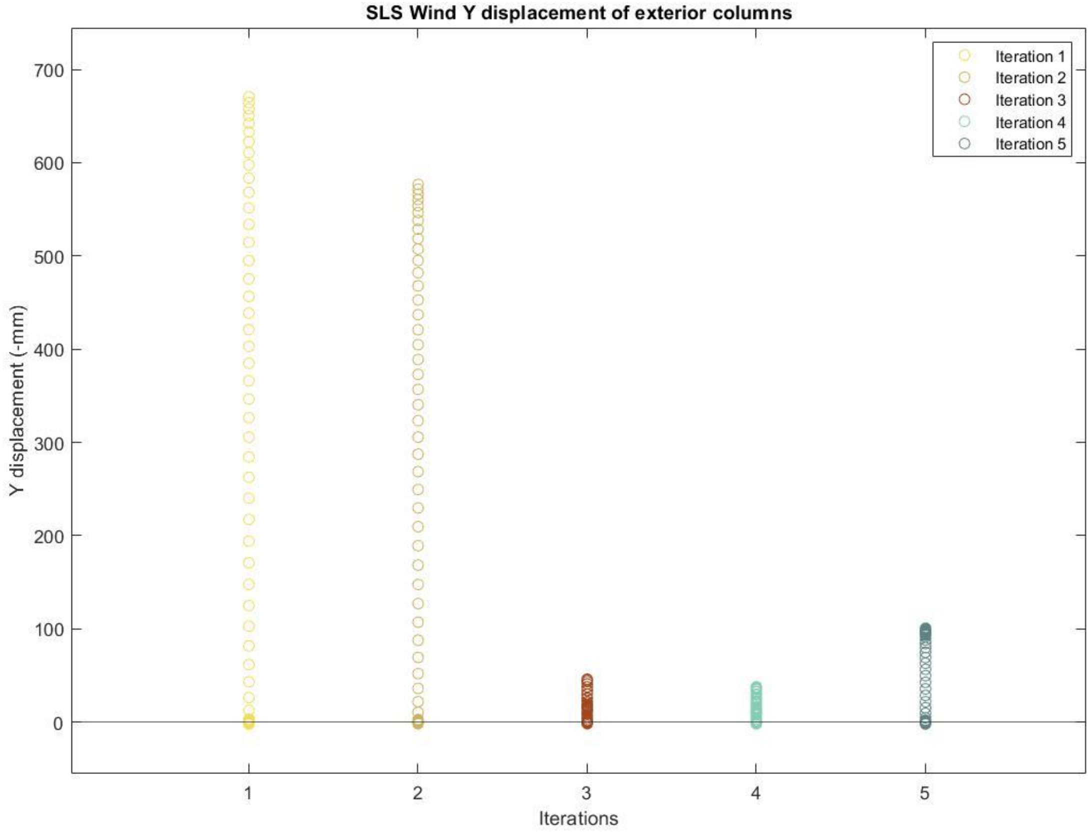


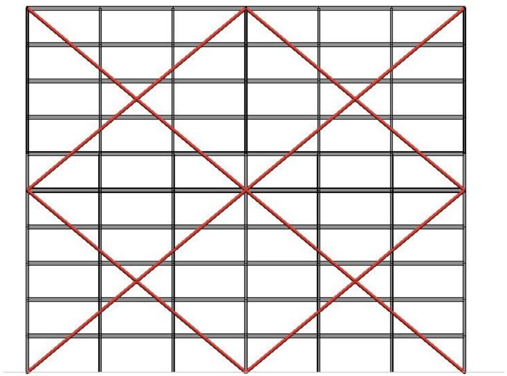




X side section view SLS wind deformation

Final iteration and justifications





Chosen iteration (number 4)

- Iteration 4 is the most optimal
- Might need to put braces just on one side to not have problems due to thermal expansion
- For further iterations we could change braces type to make the structure less heavy

Thank you!

ARUP
FSGEC

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