Pell Frischmann

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Centre of Research for Rare Diseases in Children (CRRDC)

PREDICTED GROUND MOVEMENT REPORT

Doc. Ref. No: PF-12692-RP-0012
Revision: 0
Issue Date: 06.02.15

Submitted by Pell Frischmann

REVISION RECORD					
Rev	**Description**	**Date**	**Originator**	**Checked**	**Approved**
0	FIRST ISSUE	06.02.15	AMD	YOG	MN

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1.0 INTRODUCTION:

This document was prepared by Pell Frischmann in order to:

- Present the predicted ground movement due to proposed ground works at CRRDC (the site) and
- Assess the potential impact of the predicted ground movements to No. 4 Guilford Place building.

For the purposes of this report, the most onerous part of the site has been taken into consideration. The section analysed west of the site, to the back of No. 4 Guildford Place.

This document described the methodology and assumptions for the calculation of the predicted ground movements and a damage assessment for the No. 4 Guilford Place building.

Predicted ground movements presented within this document are based on:

- CIRIA C580, Embedded Retaining Walls – Guidance for Economic Design, and EC7 – Geotechnical Design.

The methodology for the damage assessment for No. 4 Guilford Place bBuilding in this report was based on:

- CIRIA Special Publication 201 – Response of buildings to excavation induced ground movements.
- Burland, J.B. and Worth, C.P. (1974). Settlement of buildings and associated damage. Proc. Conference on Settlement of Structures, Cambridge. Pentech Press.

2.0 PROPOSED CONSTRUCTION WORKS:

The redevelopment of the site will entail a double storey deep basement (approx. 8.75m deep), with a proposed sheet pile wall that penetrates at least 2m into the London Clay in order to form a water tight seal. General basement and building information used within this document is presented in Table 1 below:

Table 1: General basement and building information

Item	Description
Basement Storeys	2
Wall type forming the basement	AZ34
Capping Level (mOD)	19.915
Excavation Level (mOD)	11.2
Nearest distance from basement to No. 4 Guilford Place (m)	2.25
Foundation Type and Building Type of No. 4 Guilford Place	Strip footings, Missionary Building.

3.0 PREDICTED GROUND MOVEMENTS:

Ground movements behind the retaining wall are assumed to be "greenfield" ground movements and no account has been taken of the stiffening effects of existing underground structures in the vicinity of No.4 Guildford Place and the retaining wall.

A conservative approach has been taken in order to predict the horizontal and vertical ground movements behind the sheet pile wall associated with the excavation in front of the sheet pile wall for the construction of the basement. Hence predicted ground movements at No.4 Guildford Place structure are likely to be conservative.

The CIRIA C580 methodology for predicting horizontal and vertical ground movements is outlined in Figure 1 below. In this approach the deflected horizontal profile of the wall in the vertical plane is rotated into the horizontal plane, and the magnitude of the predicted vertical ground displacements are derived as a proportion of the horizontal wall displacements.

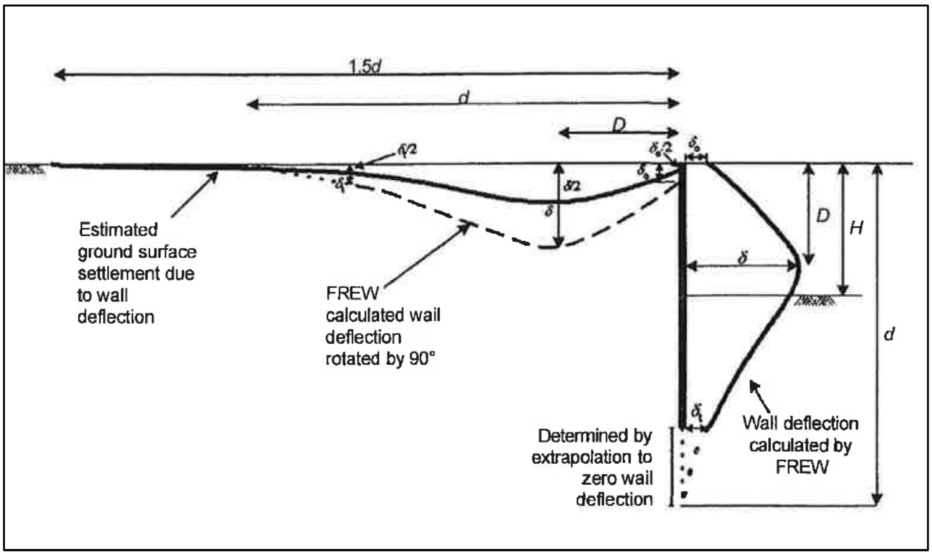


Figure 1: Relationship between analysed lateral (propped) wall deflections and predicted ground surface settlements in stiff soil.

The deflected horizontal profile of the sheet pile wall, constructed using AZ34 sections, was undertaken using WALLAP in accordance with EC7 – Geotechnical Design.

Ground movements due to long-term settlement/heave due to the excavation of the basement have not been included. These movements are expected be small and uniform.

3.1. Assumptions

The stiffness of the existing subsurface structures such as foundations has not been taken into account in the calculation of the predicted ground movements. The following construction sequence has been adopted in order to predict the deflected horizontal profile of the sheet pile wall:

1. Apply Surcharge 32kN/m^2.
2. Apply Surcharge 52.6kN/m^2.
3. Excavate berm for piling platform. Piling platform level 19.57mOD. Toe of Berm 18.57mOD.
4. Excavate to 18.91mOD.
5. Install temporary prop at 19.53mOD.
6. Excavate to 15.37mOD.
7. Install temporary prop at 16mOD.
8. Excavate to 11.2mOD.
9. Install B2 Slab.
10. Install B1 Slab.
11. Remove temporary prop at 16mOD.
12. Remove temporary prop at 19.53mOD.
13. Install Ground Floor Slab.

The following assumptions were made in the WALLAP analysis:

- Near footing of No. 4 Guildford Place is approx. 2.25m from the sheet pile wall.
- Foundation level of No. 4 Guildford Place is approx. 19.73mOD.
- Surcharge load due to the 2 story part of No. 4 Guildford Place is 32kN/m^2.
- Surcharge load due to the 4 story part of No. 4 Guildford Place is 52.6kN/m^2.
- The surcharge from No. 4 Guildford Place will be directly taken by the sheet pile wall and not the existing wall between the sheet pile wall and No. 4 Guildford Place.
- Prop size of CHS 244.5 x 12.5

4.0 RESULTS

4.1. Predicted Ground Movements

Horizontal wall movements from WALLAP indicates that the maximum wall movement is 11mm. Results from WALLAP are included in Appendix 1.

In order to calculate the predicted vertical ground movement behind the retaining wall the CIRIA C580 approach outlined in Section 3 and summarised in Figure 1 was applied. Hence maximum predicted vertical ground movement at No.4 Guildford Place is 5.5mm. This location is a point of inflection and it is considered the worst case of horizontal compressive strain in the context of damage assessment. Figure 2 shows a typical situation of a building adjacent to an excavation and the inflection point.

In order to predict the horizontal ground movement behind the retaining wall, empirical relationships presented in CIRIA C580 relating the horizontal ground movements to the excavation depth were used. These relationships (2.11(a) in CIRIA C580) are reproduced in Appendix 2. A moderate propping stiffness for predicting horizontal movements was assumed. Hence maximum predicted horizontal ground movements are 22mm, 17mm and 9mm at the near, mid and far footing respectively of No.4 Guildford Place from the retaining wall.

A typical situation that may exist is shown in Figure 2 below.

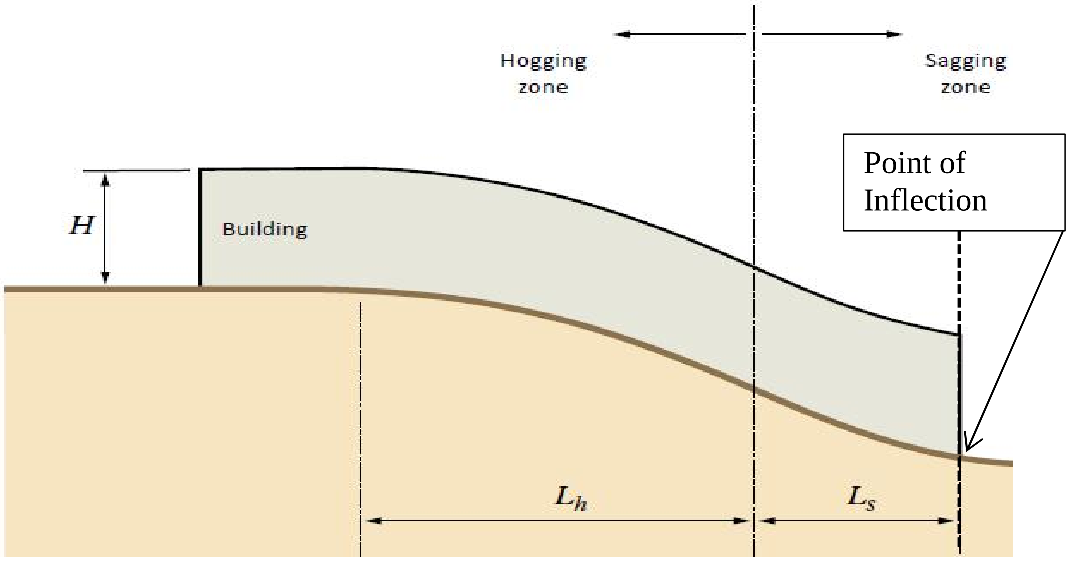


Figure 2: General case of a building affected by an excavation nearby

A summary of the predicted ground movements at No.4 Guildford Place is presented in Table 2 below:

Table 2: Summary of predicted ground movements

Building	**Analysis Location under Building**	**Distance from Retaining wall (m)**	**Maximum Vertical Movement (mm)**	**Maximum Vertical Movement measured at under centre point of the footing (mm)**	**Maximum Horizontal Movement (mm)**
No.4 Guildford	Nearest Foundation to Retaining wall	6	5.5	5	22
	Mid Foundation to Retaining wall	12	3.2		17
	Farest Foundation to Retaining wall	21	1	1.5	9

In this case the vertical differential movement between hogging zone of the building and the sagging zone of the building are 0.5mm and 0.25mm respectively. These have been used to calculate the Horizontal strains, which have been used to calculate the total bending strain and the maximum tensile strain due to diagonal distortion.

4.2. Results of damage assessment

It should be noted that to ensure the soil-structure interaction is accounted for, it is important to take into consideration the building stiffness. As a result the strains due to ground settlement, considering the building stiffness were calculated using the approach as outlined by Burland, et Al (1974). (See Appendix 3 for results).

The following assumptions were made using the approach as outlined by Burland, et Al (1974):

- The point of inflection is taken as the max. displacement of 5.5mm.
- The zone between sagging and hogging is established as the point of where the ground is neither sagging nor hogging. In this case it is approx. 1.75m from location where the building splits from 2 floors to 4 floors. There 4 floors are in the hogging zone and 2 floors are in the sagging zone.

The result of the damage assessment undertaken for No.4 Guildford Place is considered to be conservative due to the assumptions described in section 3.1. A summary of the results are presented in Table 3:

Table 3: Results from Damage Assessment

		No. 4 Guilford Place	
Differential Vertical Ground Movement (mm)		0.25	0.5
Diffential Horizontal Ground Movement (mm)		5	8
Hogging/sagging		Sagging Zone	Hogging Zone
Strain Component (%)	Horizontal	0.000833	0.000889
	Bending	0.0000511	0.00003096
	Diagonal	0.0000332	0.00005366
Total/Maximum Strain (%)	Bending	0.0007819	0.0009198
	Tensile	0.000702	0.00089
Damage Category		0	0

5.0 DAMAGE CATEGORY:

From the predicted maximum tensile stress of No. 4 Guildford Place in the sagging and hogging zones it is possible to categorise the potential damage caused to the structure. This has been based on visible damage criteria of Burland *et al* (1977) as modified by Boscardin and Cording (1989) and Burland (2001) and is the criteria incorporated into the CIRIA C580 methodology, refer to Appendix 4.

From the predicted maximum tensile stress in the sagging and hogging zones of No. 4 Guildford Place indicates the damage Category 0 assessment characterised by 'Negligible visible damage' with crack widths of < 0.1mm.

6.0 SUMMARY:

The calculations presented herein demonstrate that No. 4 Guildford Place will be not be affected by horizontal or vertical ground movement associated excavation in front of the sheet pile wall for the construction of the basement structure at CRRDC.

From the assessment carried out, the potential building damage falls just within the CIRIA C580 Category 0 Damage Classification, with visible damage likely to be negligible.

It should be noted that the analysis presented here can be considered conservative. In order to obtain more accurate predictions of likely ground movements and potential building damage to adjacent structures, a more rigorous analysis such as a finite element study would be required. However based on the findings within this report this would not be considered necessary.

Appendix 1

Units: kN,m

INPUT DATA

SOIL PROFILE

Stratum no.	Elevation of top of stratum	Soil types - Active side	Soil types - Passive side
1	19.73	1 Made Ground	1 Made Ground
2	16.50	2 WLC	2 WLC
3	14.50	3 London Clay (UD)	3 London Clay (UD)
4	2.80	5 Lambeth Group (UD)	5 Lambeth Group (UD)

SOIL PROPERTIES

-- Soil type -- No.	Description (Datum elev.)	Bulk density kN/m3	Young's Modulus Eh,kN/m2 (dEh/dy)	At rest coeff. Ko (dKo/dy)	Consol state. NC/OC (Nu)	Active limit Ka (Kac)	Passive limit Kp (Kpc)	Cohesion kN/m2 (dc/dy)
1	Made Ground	18.00	10000	0.577	OC	0.353	3.413	
					(0.200)	(0.000)	(0.000)	
2	WLC	20.00	43000	1.000	OC	1.000	1.000	43.00u
	(16.50)		(6900)		(0.490)	(2.389)	(2.390)	(6.900)
3	London Cl..	20.00	56000	1.000	OC	1.000	1.000	56.00u
	(14.50)		(6900)		(0.490)	(2.389)	(2.390)	(6.900)
4	London Cl..	20.00	44800	1.000	OC	0.383	3.044	4.000d
	(14.50)		(5520)		(0.200)	(1.452)	(4.816)	
5	Lambeth G..	21.00	170000	1.000	OC	1.000	1.000	170.0u
	(2.80)		(4900)		(0.490)	(2.000)	(2.000)	(4.900)
6	Lambeth G..	21.00	136000	1.000	OC	0.417	2.726	10.00d
	(2.80)		(3920)		(0.200)	(1.520)	(4.496)	

Additional soil parameters associated with Ka and Kp

------- Soil type ------- No.	Description	Ka: Soil friction angle	Ka: Wall adhesion coeff.	Ka: Back-fill angle	Kp: Soil friction angle	Kp: Wall adhesion coeff.	Kp: Back-fill angle
1	Made Ground	25.00	0.642	0.00	25.00	0.642	0.00
2	WLC	0.00	0.500	0.00	0.00	0.500	0.00
3	London Clay (UD)	0.00	0.500	0.00	0.00	0.500	0.00
4	London Clay (D)	23.00	0.646	0.00	23.00	0.646	0.00
5	Lambeth Group (UD)	0.00	0.000	0.00	0.00	0.000	0.00
6	Lambeth Group (D)	21.00	0.650	0.00	21.00	0.650	0.00

GROUND WATER CONDITIONS

Density of water = 10.00 kN/m3

	Active side	Passive side
Initial water table elevation	18.91	18.91

Automatic water pressure balancing at toe of wall : No

Water press. profile no.	Active: Point no.	Active: Elev. m	Active: Piezo elev. m	Active: Water press. kN/m2	Passive: Point no.	Passive: Elev. m	Passive: Piezo elev. m	Passive: Water press. kN/m2	
1	1	18.91	18.91	0.0	1	14.93	14.93	0.0	MC+WC
2	1	18.91	18.91	0.0	1	11.20	11.20	0.0	MC+WC

WALL PROPERTIES

Type of structure = Fully Embedded Wall
Elevation of toe of wall = 3.00
Maximum finite element length = 1.00 m
Youngs modulus of wall E = 2.1000E+08 kN/m2
Moment of inertia of wall I = 7.8700E-04 m4/m run
(Arcelor AZ34) E.I = 165270 kN.m2/m run
Yield Moment of wall = Not defined

STRUTS and ANCHORS

Strut/ anchor no.	Elev.	Strut spacing m	X-section area of strut sq.m	Youngs modulus kN/m2	Free length m	Inclin -ation (degs)	Pre-stress /strut kN	Tension allowed
1	19.53	8.00	0.036440	2.000E+08	5.00	0.00	0	No
2	16.00	8.00	0.036440	2.000E+08	5.00	0.00	0	No
3	16.78	1.00	0.340000	2.000E+07	5.00	0.00	0	No
4	11.90	1.00	1.100000	2.000E+07	5.00	0.00	0	No

SURCHARGE LOADS

Surch -arge no.	Elev.	Distance from wall	Length parallel to wall	Width perpend. to wall	Surcharge ----- kN/m2 ----- Near edge	Far edge	Equiv. soil type	Partial factor/ Category
1	19.73	2.25(A)	20.00	8.00	32.00	=	N/A	1.00 P/U
2	19.73	10.25(A)	20.00	10.70	52.60	=	N/A	1.00 P/U

Note: A = Active side, P = Passive side
Limit State Categories P/U = Permanent Unfavourable
P/F = Permanent Favourable
Var = Variable (unfavourable)

CONSTRUCTION STAGES

Construction stage no.	Stage description
1	Apply surcharge no.1 at elevation 19.73
2	Excavate to elevation 19.57 on PASSIVE side Toe of berm at elevation 18.57 Width of top of berm = 8.90 Width of toe of berm = 11.84
3	Apply water pressure profile no.1 (Mod. Conserv.)
4	Excavate to elevation 18.91 on PASSIVE side
5	Install strut or anchor no.1 at elevation 19.53
6	Excavate to elevation 15.37 on PASSIVE side
7	Install strut or anchor no.2 at elevation 16.00
8	Apply water pressure profile no.2 (Mod. Conserv.)
9	Excavate to elevation 11.20 on PASSIVE side
10	Fill to elevation 11.35 on PASSIVE side with soil type 1
11	Install strut or anchor no.4 at elevation 11.90
12	Install strut or anchor no.3 at elevation 16.78
13	Remove strut or anchor no.2 at elevation 16.00
14	Remove strut or anchor no.1 at elevation 19.53
15	Change properties of soil type 3 to soil type 4 Ko pressures will not be reset
16	Change properties of soil type 2 to soil type 4 Ko pressures will not be reset
17	Change properties of soil type 5 to soil type 6 Ko pressures will not be reset

FACTORS OF SAFETY and ANALYSIS OPTIONS

Limit State options: Serviceability Limit State
All loads and soil strengths are unfactored

Stability analysis:
Method of analysis - Strength Factor method
Factor on soil strength for calculating wall depth = 1.00

Parameters for undrained strata:
Minimum equivalent fluid density = 10.00 kN/m3
Maximum depth of water filled tension crack = 0.00 m

Bending moment and displacement calculation:
Method - Subgrade reaction model using Influence Coefficients
Open Tension Crack analysis? - No
Non-linear Modulus Parameter (L) = 0 m

Boundary conditions:
Length of wall (normal to plane of analysis) = 80.00 m

Width of excavation on active side of wall = 20.00 m
Width of excavation on passive side of wall = 20.00 m

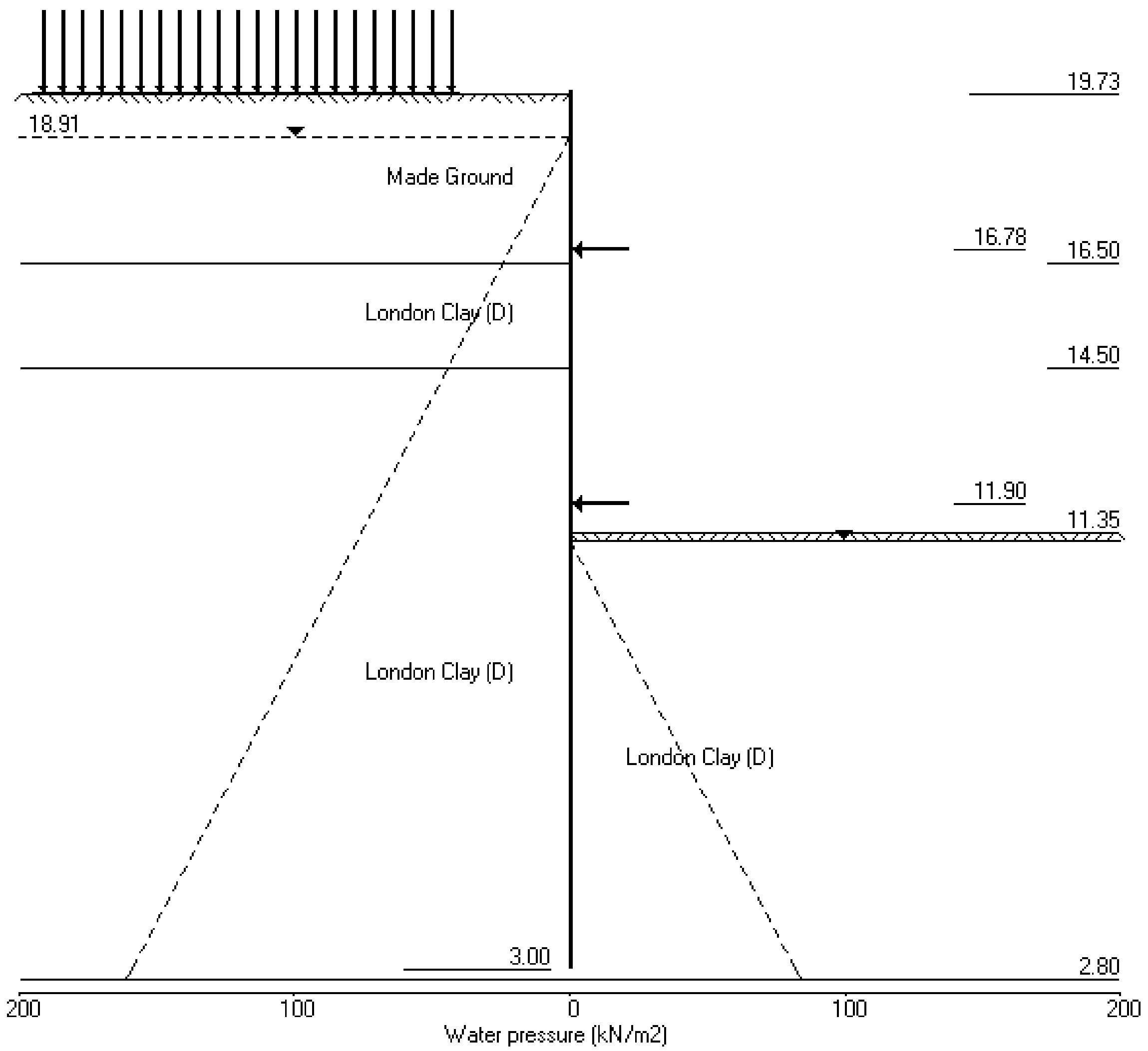
Distance to rigid boundary on active side = 20.00 m
Distance to rigid boundary on passive side = 20.00 m

OUTPUT OPTIONS

Stage no.	Stage description	Output options: Displacement Bending mom. Shear force	Active, Passive pressures	Graph. output
1	Apply surcharge no.1 at elev. 19.73	No	No	No
2	Excav. to elev. 19.57 on PASSIVE side	No	No	No
3	Apply water pressure profile no.1	No	No	No
4	Excav. to elev. 18.91 on PASSIVE side	No	No	No
5	Install strut no.1 at elev. 19.53	No	No	No
6	Excav. to elev. 15.37 on PASSIVE side	No	No	No
7	Install strut no.2 at elev. 16.00	No	No	No
8	Apply water pressure profile no.2	No	No	No
9	Excav. to elev. 11.20 on PASSIVE side	No	No	No
10	Fill to elev. 11.35 on PASSIVE side	No	No	No
11	Install strut no.4 at elev. 11.90	No	No	No
12	Install strut no.3 at elev. 16.78	No	No	No
13	Remove strut no.2 at elev. 16.00	No	No	No
14	Remove strut no.1 at elev. 19.53	No	No	No
15	Change soil type 3 to soil type 4	No	No	No
16	Change soil type 2 to soil type 4	No	No	No
17	Change soil type 5 to soil type 6	No	No	No
*	Summary output	Yes	-	Yes

Units: kN,m

Stage No.17 Change soil type 5 to soil type 6



Units: kN,m

Summary of results

LIMIT STATE PARAMETERS

Limit State: Serviceability Limit State

All loads and soil strengths are unfactored

STABILITY ANALYSIS of Fully Embedded Wall according to Strength Factor method

Factor of safety on soil strength

				FoS for toe elev. = 3.00		Toe elev. for FoS = 1.000	
Stage No.	--- G.L. --- Act.	Pass.	Strut Elev.	Factor of Safety	Moment equilib. at elev.	Toe elev.	Wall Penetr -ation
1	19.73	19.73	Cant.	Conditions not suitable for FoS calc.			
2	19.73	19.57	Cant.	Conditions not suitable for FoS calc.			
3	19.73	19.57	Cant.	Conditions not suitable for FoS calc.			
4	19.73	18.91	Cant.	9.475	4.51	18.40	0.51
5	19.73	18.91		No analysis at this stage			
6	19.73	15.37	19.53	5.092	n/a	14.69	0.68
7	19.73	15.37		No analysis at this stage			

All remaining stages have more than one strut - FoS calculation n/a

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Units: kN,m

Summary of results

BENDING MOMENT and DISPLACEMENT ANALYSIS of Fully Embedded Wall

Analysis options

Length of wall perpendicular to section = 80.00m
Subgrade reaction model - Boussinesq Influence coefficients
Soil deformations are elastic until the active or passive limit is reached
Open Tension Crack analysis - No

Rigid boundaries: Active side 20.00 from wall
Passive side 20.00 from wall

Limit State: Serviceability Limit State

Calculated Bending Moments and Strut Forces have been multiplied by a factor of 1.35 to obtain values for structural design.

Bending moment, shear force and displacement envelopes

Node	Y	Displacement		---- Bending moment ----				------- Shear force ------			
no.	coord			Calculated		Factored		Calculated		Factored	
		max.	min.	max.	min.	max.	min.	max.	min.	max.	min.
		m	m	kN.m/m		kN.m/m		kN/m	kN/m	kN/m	kN/m
1	19.73	0.004	0.000	0	-0	0	-0	0	0	0	0
2	19.57	0.004	0.000	0	0	0	0	1	-0	1	-0
3	19.53	0.004	0.000	0	-0	0	-0	1	-48	1	-64
4	18.91	0.005	0.000	2	-29	3	-39	6	-46	8	-62
5	18.57	0.005	0.000	5	-44	7	-59	10	-43	14	-58
6	17.68	0.006	0.000	22	-76	29	-103	27	-28	37	-38
7	16.78	0.007	0.000	57	-91	77	-123	54	-141	73	-191
8	16.50	0.007	0.000	43	-90	58	-122	53	-131	71	-177
9	16.00	0.008	0.000	73	-82	99	-111	70	-153	95	-206
10	15.37	0.010	0.000	21	-106	28	-143	51	-127	69	-172
11	14.93	0.010	0.000	20	-139	27	-188	43	-107	58	-144
12	14.50	0.011	0.000	18	-164	24	-222	34	-85	46	-115
13	13.75	0.011	0.000	13	-184	18	-248	32	-43	43	-59
14	13.00	0.011	0.000	12	-172	17	-232	93	-6	125	-8
15	12.45	0.010	0.000	17	-159	23	-215	142	-5	191	-6
16	11.90	0.010	0.000	72	-124	97	-168	195	-158	264	-213
17	11.35	0.009	0.000	19	-66	25	-89	130	-100	175	-136
18	11.20	0.009	0.000	19	-45	25	-61	143	-84	193	-114
19	10.60	0.009	0.000	42	-51	57	-69	89	-39	121	-53
20	10.00	0.009	0.000	75	-61	101	-83	44	-4	60	-5
21	9.00	0.008	0.000	77	-49	104	-67	34	-10	46	-13
22	8.00	0.007	0.000	58	-12	79	-16	44	-23	60	-31
23	7.00	0.006	0.000	34	0	46	0	28	-21	38	-29
24	6.00	0.005	0.000	44	0	59	0	3	-14	3	-19
25	5.00	0.004	0.000	36	0	48	0	0	-12	0	-17
26	4.00	0.003	0.000	18	0	25	0	0	-17	0	-24
27	3.00	0.003	0.000	0	-0	0	-0	0	0	0	0

Summary of results (continued)

Calculated Bending Moments and Strut Forces have been multiplied by a factor of 1.35 to obtain values for structural design.

Maximum and minimum bending moment and shear force at each stage

Stage	Bending moment						Shear force					
	Calculated				Factored		Calculated				Factored	
no.	max. kN.m/m	elev.	min. kN.m/m	elev.	max. kN.m/m	min. kN.m/m	max. kN/m	elev.	min. kN/m	elev.	max. kN/m	min. kN/m
1	1	7.00	-4	14.50	2	-6	1	11.90	-2	17.68	2	-2
2	1	7.00	-4	14.50	2	-5	1	11.35	-1	17.68	1	-2
3	8	14.93	-4	17.68	11	-5	12	16.50	-3	18.57	16	-4
4	21	15.37	-0	19.73	28	-0	16	16.50	-7	13.75	22	-9
5	No calculation at this stage											
6	19	11.35	-91	16.78	25	-123	51	15.37	-48	19.53	69	-64
7	No calculation at this stage											
8	18	11.90	-90	16.78	24	-122	51	15.37	-47	19.53	69	-64
9	76	9.00	-171	13.00	102	-231	142	11.20	-153	16.00	191	-206
10	77	9.00	-172	13.00	103	-232	143	11.20	-153	16.00	193	-206
11	No calculation at this stage											
12	No calculation at this stage											
13	77	9.00	-184	13.75	104	-248	123	11.90	-141	16.78	167	-191
14	77	9.00	-184	13.75	104	-248	123	11.90	-141	16.78	167	-191
15	71	11.90	-132	14.50	96	-178	194	11.90	-158	11.90	262	-213
16	72	11.90	-134	14.50	97	-181	195	11.90	-158	11.90	264	-213
17	72	11.90	-134	14.50	97	-181	195	11.90	-158	11.90	264	-213

Maximum and minimum displacement at each stage

Stage	Displacement				Stage description
no.	maximum m	elev.	minimum m	elev.	
1	0.001	14.93	0.000	19.73	Apply surcharge no.1 at elev. 19.73
2	0.001	16.00	0.000	19.73	Excav. to elev. 19.57 on PASSIVE side
3	0.002	19.73	0.000	19.73	Apply water pressure profile no.1
4	0.004	19.73	0.000	19.73	Excav. to elev. 18.91 on PASSIVE side
5	No calculation at this stage				Install strut no.1 at elev. 19.53
6	0.006	16.50	0.000	19.73	Excav. to elev. 15.37 on PASSIVE side
7	No calculation at this stage				Install strut no.2 at elev. 16.00
8	0.006	16.50	0.000	19.73	Apply water pressure profile no.2
9	0.010	13.00	0.000	19.73	Excav. to elev. 11.20 on PASSIVE side
10	0.010	13.00	0.000	19.73	Fill to elev. 11.35 on PASSIVE side
11	No calculation at this stage				Install strut no.4 at elev. 11.90
12	No calculation at this stage				Install strut no.3 at elev. 16.78
13	0.011	13.75	0.000	19.73	Remove strut no.2 at elev. 16.00
14	0.011	13.75	0.000	19.73	Remove strut no.1 at elev. 19.53
15	0.010	13.75	0.000	19.73	Change soil type 3 to soil type 4
16	0.010	13.75	0.000	19.73	Change soil type 2 to soil type 4
17	0.010	13.75	0.000	19.73	Change soil type 5 to soil type 6

Summary of results (continued)

Calculated Bending Moments and Strut Forces have been multiplied by a factor of 1.35 to obtain values for structural design.

Strut forces at each stage (horizontal components)

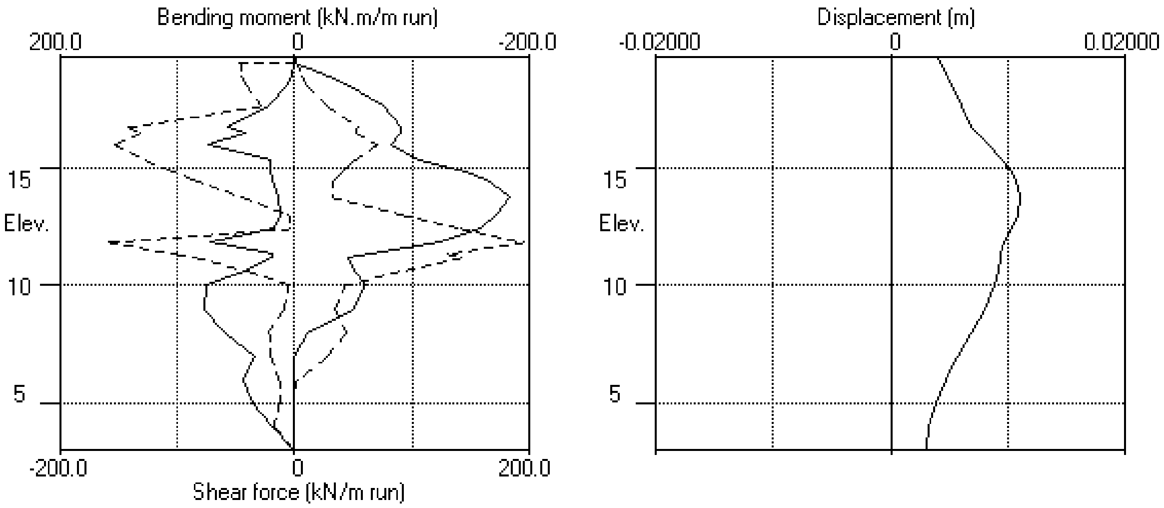
Stage no.	Strut no. 1 at elev. 19.53			Strut no. 2 at elev. 16.00			Strut no. 3 at elev. 16.78		
	--Calculated--		Factored	--Calculated--		Factored	--Calculated--		Factored
	kN per m run	kN per strut	kN per strut	kN per m run	kN per strut	kN per strut	kN per m run	kN per strut	kN per strut
6	48	382	516	---	---	---	---	---	---
8	48	380	513	1	4	6	---	---	---
9	5	39	53	223	1781	2405	---	---	---
10	5	40	54	223	1781	2404	---	---	---
13	slack	slack	slack	---	---	---	196	196	264
14	---	---	---	---	---	---	196	196	264
15	---	---	---	---	---	---	178	178	241
16	---	---	---	---	---	---	181	181	245
17	---	---	---	---	---	---	181	181	245

Stage no.	Strut no. 4 at elev. 11.90		
	--Calculated--		Factored
	kN per m run	kN per strut	kN per strut
13	60	60	80
14	60	60	80
15	352	352	475
16	353	353	477
17	353	353	477

PELL FRISCHMANN CONSULTANTS LTD | Sheet No.
Program: WALLAP Version 6.05 Revision A43.B57.R48 | Job No. A12692
Licensed from GEOSOLVE | Made by : AMD
Data filename/Run ID: Sheet Pile Wall, GOSH_SLS |
Great Ormand Street Hospital | Date: 4-02-2015
Sheet Pile Wall - Section 1 | Checked :

Units: kN,m

Bending moment, shear force, displacement envelopes



Appendix 2

Pell Frischmann

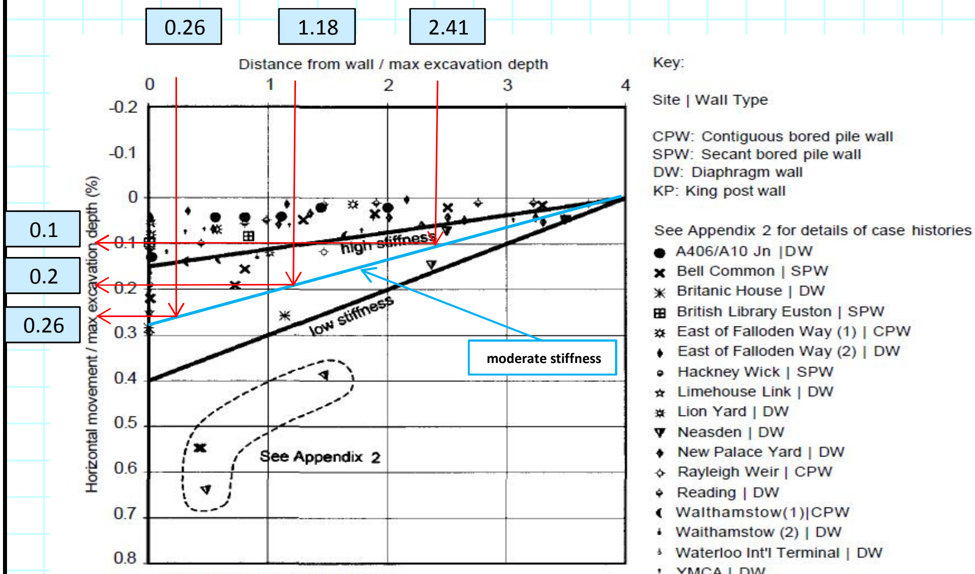
CALCULATIONS	Project: CRRDC	Project/Calc No. A12692	Sheet No. 1	Date 03.02.15

Subject: Predicted ground movements in accordance with CIRIA C580 - No.4 Guildford Place

By: AMD | Chkd:

Ref. | Output

Excavation: Section 1



(a) Horizontal movements

Near Footing:

$$\frac{\textit{Distance from wall}}{\textit{Max. excavation depth}} = \frac{2.25 \text{ m}}{8.7 \text{ m}} = 0.26$$

$$\frac{\textit{Horizontal movement}}{\textit{Max. excavation depth}} = \frac{\chi \text{ mm}}{8700 \text{ mm}} = 0.26 \%$$

Therefore: χ = 22.4 mm horizontal movement

Mid Footing:

$$\frac{\textit{Distance from wall}}{\textit{Max. excavation depth}} = \frac{10.25 \text{ m}}{8.7 \text{ m}} = 1.18$$

$$\frac{\textit{Horizontal movement}}{\textit{Max. excavation depth}} = \frac{\chi \text{ mm}}{8700 \text{ mm}} = 0.20 \%$$

Therefore: χ = 17.4 mm horizontal movement

Far Footing:

$$\frac{\textit{Distance from wall}}{\textit{Max. excavation depth}} = \frac{21 \text{ m}}{8.7 \text{ m}} = 2.41$$

$$\frac{\textit{Horizontal movement}}{\textit{Max. excavation depth}} = \frac{\chi \text{ mm}}{8700 \text{ mm}} = 0.10 \%$$

Therefore: χ = 8.7 mm horizontal movement

Ref.

Output

Total Horizontal Movement

Near Footing: = $Movement\ due\ to\ Installation + Movement\ due\ to\ excavation$

= 22 mm

Mid Footing: = $Movement\ due\ to\ Installation + Movement\ due\ to\ excavation$

= 17 mm

Far Footing: = $Movement\ due\ to\ Installation + Movement\ due\ to\ excavation$

= 9 mm

Differential Movement

Differential movement Δ = $Near\ footing\ movement - Mid\ footing\ movement$

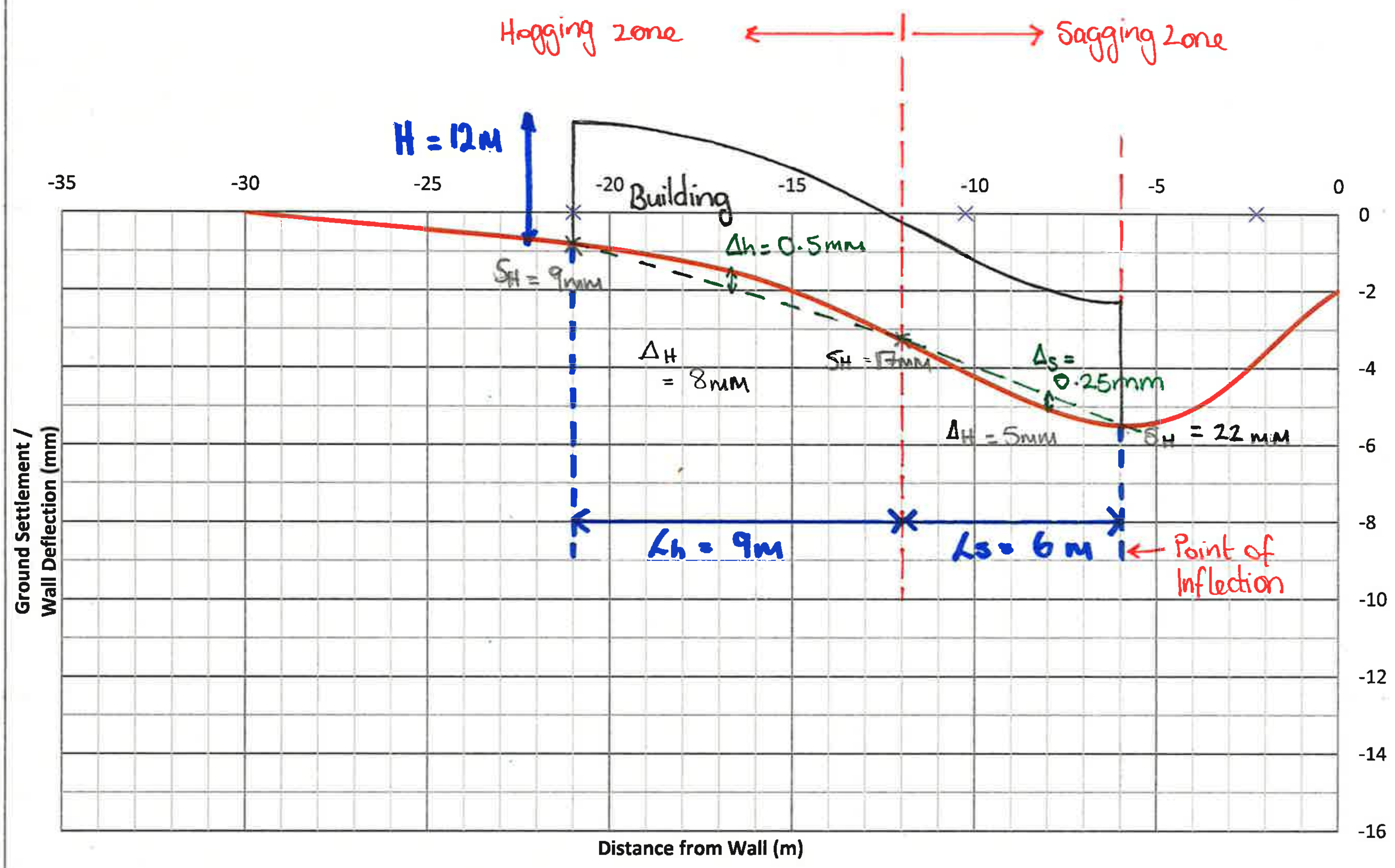
= 5 mm

Differential movement Δ = $Mid\ footing\ movement - Far\ footing\ movement$

= 8 mm

Appendix 3

Relationship between analysed AZ 34 Sheet Pile proped wall deflections and predicted ground surface settlements .



Pell Frischmann

Project/Calc No. A12692

Sheet No. 1

CALCULATIONS

Project CRRDC

Date. 04-02-15

Subject Predicted Ground Movements — No.4 Guildford Place.

by AMD. Chkd

Ref.

Output

Note: For Masionary Building $\frac{E}{G} = 2.6$

$$\frac{\Delta}{L} = \left\{ \frac{L}{12t} + \frac{3I}{2tLH} \frac{E}{G} \right\} \varepsilon_b \qquad (1)$$

$$\frac{\Delta}{L} = \left\{ 1 + \frac{HL^2}{18I} \frac{G}{E} \right\} \varepsilon_d \qquad (2)$$

$$\varepsilon_{bt} = \varepsilon_h + \varepsilon_b \qquad (4)$$

$$\varepsilon_{dt} = 0.35\,\varepsilon_h + [(0.65\,\varepsilon_h)^2 + \varepsilon_d^2]^{0.5} \qquad (5)$$

$$\varepsilon_h = \frac{\Delta_H}{L} \qquad (3)$$

Hogging Zone

$H = 12\ m$
$L = 9\ m$
$\frac{E}{G} \doteq 2.6$
$I = \frac{H^3}{3} = 576 m^3$
$\Delta s = 0.0005\ m$
$t_h = 12\ m$
$\Delta_H = 0.008\ m$

(1) $\frac{0.0005}{9} = \left\{ \frac{9}{2(12)} + \frac{3(576)}{2(12)(9)(12)} \cdot 2.6 \right\} \varepsilon_b$

$0.556\times10^{-4} = \{0.0625 + 1.733\} \varepsilon_b$

$\varepsilon_b = \frac{0.556\times10^{-4}}{1.7958}$

$\varepsilon_b = \underline{\underline{0.00003096}}$

(2) $\frac{0.0005}{9} = \left\{ 1 + \frac{12(9)^2}{18(576)} \cdot \frac{1}{2.6} \right\} \varepsilon_d$

$0.556\times10^{-4} = (1.0361)\, \varepsilon_d$

$\varepsilon_d = \frac{0.556\times10^{-4}}{1.0361}$

$\varepsilon_d = \underline{\underline{0.00005366}}$

(3) $\varepsilon_h = \frac{0.008}{9} = \underline{\underline{0.000889}}$

(4) $\varepsilon_{bt} = 0.000889 + 0.00003096 = \underline{\underline{0.0009198}}$

Pell Frischmann

CALCULATIONS	Project: CRRDC	Project/Calc No. A12692	Sheet No. 2
Subject: Predicted Ground Movements - No.4 Guildford Place.		Date. 04.02.15	by AMD Chkd

(5) $\varepsilon_{dt} = 0.35(0.000889) + [(0.65(0.000889))^2 + 0.00005366^2]^{0.5}$

$\varepsilon_{dt} = 0.00031115 + 0.00058$

$\varepsilon_{dt} = \underline{\underline{0.00089}}$

Sagging Zone

(1) $\dfrac{0.00025}{6} = \left\{\dfrac{6}{12(3)} + \dfrac{3(18)}{2(3)(6)(6)} \cdot 2.6\right\}\varepsilon_b$

$0.417 \times 10^{-4} = \{0.1667 + 0.65\}\varepsilon_b$

$\varepsilon_b = \dfrac{0.417 \times 10^{-4}}{0.8167}$

$\varepsilon_b = \underline{\underline{0.0000511}}$

$H = 6m$
$L = 6m$
$\dfrac{E}{G} = 2.6$
$I = \dfrac{H^3}{12} = 18\ m^3$
$\Delta_s = 0.00025m$
$t_s = 3m$
$\Delta_H = 0.005m$

(2) $\dfrac{0.00025}{6} = \left\{1 + \dfrac{(6)(6)^2}{18(18)} \cdot \dfrac{1}{2.6}\right\}\varepsilon_d$

$0.417 \times 10^{-4} = (1.2564)\,\varepsilon_d$

$\varepsilon_d = \dfrac{0.417 \times 10^{-4}}{1.2564}$

$\varepsilon_d = \underline{\underline{0.0000332}}$

(3) $\varepsilon_h = \dfrac{0.005}{6} = \underline{\underline{0.000833}}$

(4) $\varepsilon_{bt} = 0.000833 + 0.0000511 = \underline{\underline{0.0007819}}$

(5) $\varepsilon_{dt} = 0.35(0.000833) + [(0.65(0.000833))^2 + 0.0000332^2]^{0.5}$

$\varepsilon_{dt} = 0.0002916 + 0.000672$
$= \underline{\underline{0.000702}}$

∴ Damage Category 0, Negligible affect.

Ref. | Output

Appendix 4

Classification of visible damage to walls (after Burland et al, *1977, Boscardin and Cording, 1989; and Burland, 2001)*

Category of damage	Description of typical damage (ease of repair is underlined)	Approximate crack width (mm)	Limiting tensile strain ε_{lim} (per cent)
0 Negligible	Hairline cracks of less than about 0.1 mm are classed as negligible.	< 0.1	0.0–0.05
1 Very slight	<u>Fine cracks that can easily be treated during normal decoration.</u> Perhaps isolated slight fracture in building. Cracks in external brickwork visible on inspection.	< 1	0.05–0.075
2 Slight	<u>Cracks easily filled. Redecoration probably required.</u> Several slight fractures showing inside of building. Cracks are visible externally and <u>some repointing may be required externally</u> to ensure weathertightness. Doors and windows may stick slightly.	< 5	0.075–0.15
3 Moderate	<u>The cracks require some opening up and can be patched by a mason. Recurrent cracks can be masked by suitable linings. Repointing of external brickwork and possibly a small amount of brickwork to be replaced.</u> Doors and windows sticking. Service pipes may fracture. Weathertightness often impaired.	5–15 or a number of cracks > 3	0.15–0.3
4 Severe	<u>Extensive repair work involving breaking-out and replacing sections of walls, especially over doors and windows.</u> Windows and frames distorted, floor sloping noticeably. Walls leaning or bulging noticeably, some loss of bearing in beams. Service pipes disrupted.	15–25 but also depends on number of cracks	> 0.3
5 Very severe	<u>This requires a major repair involving partial or complete rebuilding.</u> Beams lose bearings, walls lean badly and require shoring. Windows broken with distortion. Danger of instability.	usually > 25 but depends on number of cracks.	

Notes

1. In assessing the degree of damage, account must be taken of its location in the building or structure.
2. Crack width is only one aspect of damage and should not be used on its own as a direct measure of it.