APPENDIX 3
GROUND MOVEMENT ASSESSMENT

1. GROUND MOVEMENT ASSESSMENT

A Ground Movement Assessment (GMA) has been carried out in accordance with CIRIA C760 and takes into account the construction methodology and site specific ground and groundwater conditions.

All structures / properties within the zone of influence have been assessed (including buildings, tunnels, retaining walls etc) and foundation depths have been confirmed as circa 4.0 m below ground.

The design conservatively assumes that the piled wall acts as a propped cantilever for the purposes of assessing anticipated ground movements.

1.1. Zone of Influence

In accordance with CIRIA C760, the distance behind the wall to negligible movement is 1.5 x wall depth for horizontal movements and 2 x wall depth for vertical movements.

For a conservative approach, a zone of influence of **2 x wall depth** will be taken and with reference to the outline pile calculations attached to this document, a pile length of **11.0 m** will be adopted.

With this in consideration, **the zone of influence will be taken as 22.0 m**

Again conservatively, it is assumed the wall will be installed to the extents of the site boundary and therefore the plotted zone is as follows:

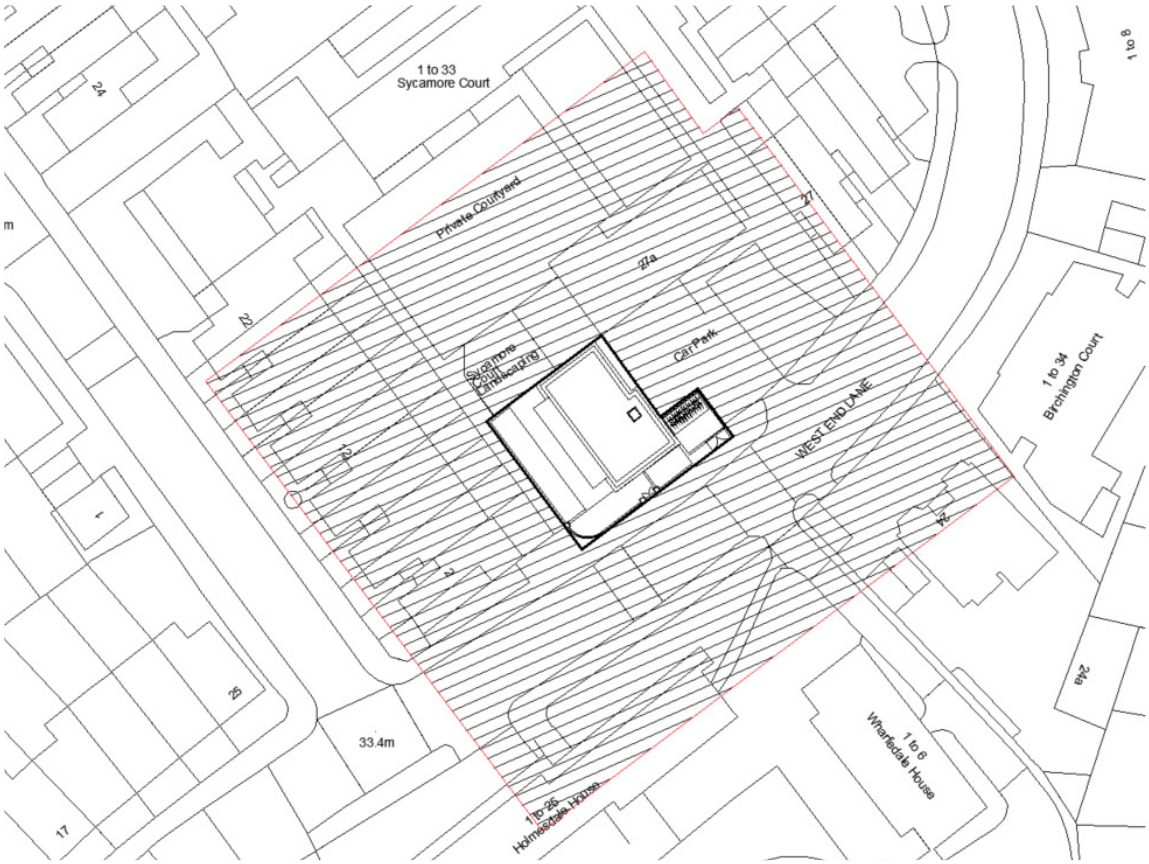


Figure 1 - Showing zone of influence plotted on OS mapping

The logic of ground movement increasing linearly with wall depth assumes the zone of influence around a singular structure (for example a singular pile of a diaphragm wall panel) extends from the toe of the wall as a cone, that spreads linearly to the ground surface.

Simply put, the closer to the piled wall, the greater the anticipated ground movement.

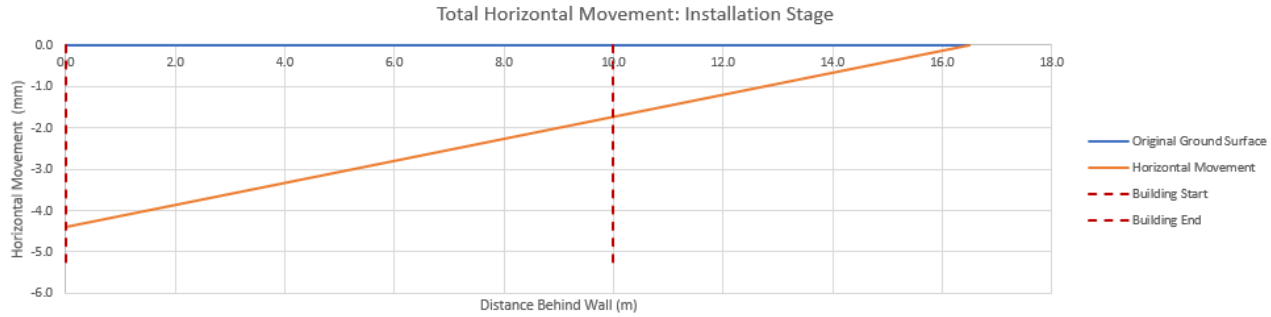
With this in consideration, it is clear from Figure 1 that the 'worst affected' adjoining building would be the nearby Sycamore Court to the North of the application site. Conservatively, the distance to the retaining wall will be taken as 0 m.

1.2. Estimated Movement Due to Installation of Wall

Therefore, using parameters from table 6.1 of CIRIA C760 for contiguous bored piles and assuming 'high stiffness' construction:

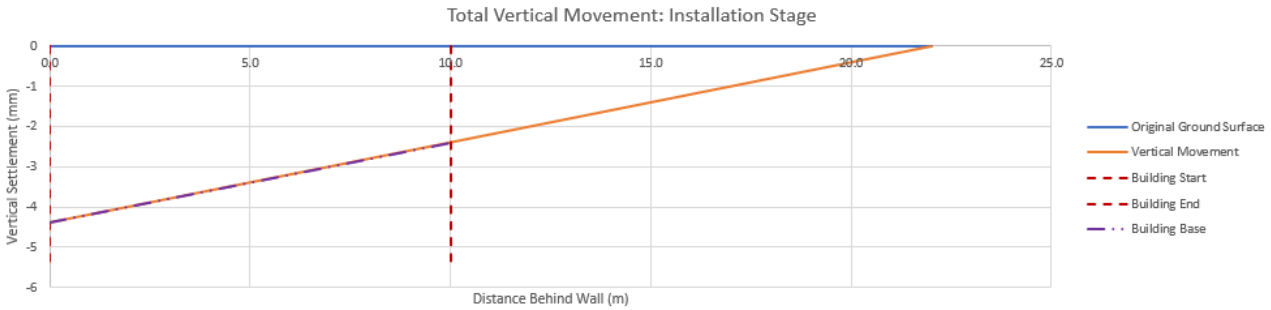
Horizontal Surface Movement / Wall Depth

Maximum horizontal movement (Max dh):	0.04 % x 11.0 m =	4.4 mm
Distance behind wall to negligible horizontal movement (L0):	1.5 x 11.0 m =	16.5 m
Gradient of horizontal movement behind wall (M):	4.4 / 16.5 =	0.27 mm/m



Vertical Surface Movement / Wall Depth

Maximum vertical movement (Max dv):	0.04 % x 11.0 m =	4.4 mm
Distance behind wall to negligible horizontal movement (L0):	2.0 x 11.0 m =	22.0 m
Gradient of vertical movement behind wall (M):	4.4 / 22.0 =	0.20 mm/m



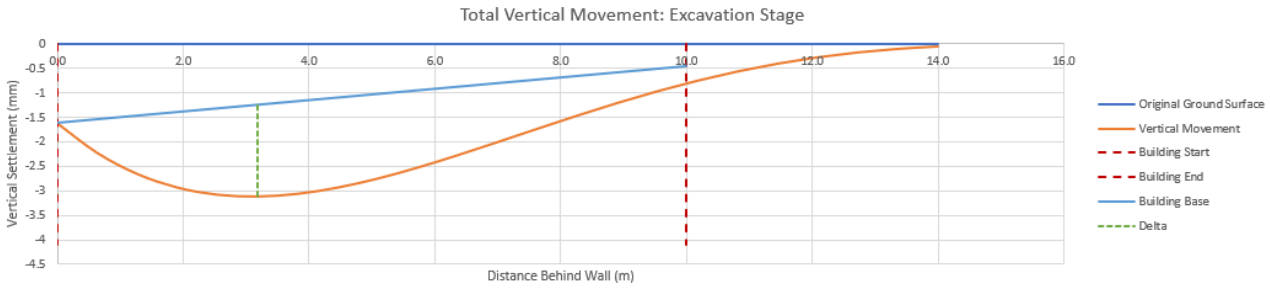
1.3. Estimated Movement Due to Excavation

Horizontal Surface Movement / Wall Depth

Maximum horizontal movement (Max dh):	0.015 % x 4.0 m =	6.0 mm
Distance behind wall to negligible horizontal movement (L0):	4.0 x 4.0 m =	16.0 m
Gradient of horizontal movement behind wall (M):	6.0 / 16.0 =	0.375 mm/m

Vertical Surface Movement / Wall Depth

Maximum vertical movement (Max dv):	0.08 % x 4.0 m =	3.2 mm
Distance behind wall to negligible horizontal movement (L0):	3.5 x 4.0 m =	14.0 m
Gradient of vertical movement behind wall (M):	3.2 / 14.0 =	0.229 mm/m



Relative movement (Delta):

Δ =	3.20 mm – 1.20 mm =	2.00 mm (at max sagging location)
Δ / L =	2.00 mm / 14.0 m =	**-0.014 %**

Total horizontal movement (excavation & installation) (dH):	4.4 + 6.0 =	**10.4 mm**
Total vertical movement (excavation & installation) (dv):	4.4 + 3.2 =	**7.6 mm**

Thus, in accordance with the Burland Scale given within Table 6.4 of CIRIA C760:

Category of Damage	Normal Degree	Limiting Tensile Strain (%)
0	**Negligible**	**0.000 % to 0.050 %**
1	Very Slight	0.050 % to 0.075 %
2	Slight	0.075 % to 0.150 %
3	Moderate	0.150 % to 0.300 %
4 to 5	Severe to Very Severe	Greater than 0.300 %

The anticipated movement is estimated to cause negligible damage to the nearby Sycamore Court.

By inspection, damage to remainder of structures within the zone of influence will be also negligible.

[Error 154 - interrupted by user]**STEEL SHEET PILING ANALYSIS & DESIGN**

In accordance with BS EN1997-1:2004 - Code of Practice for Geotechnical design and the UK National Annex

Tedds calculation version 2.0.02

Geometry

Design method	Fixed earth support
Total length of sheet pile provided	H_{pile} = **11000** mm
Number of different types of soil	N_s = **1**
Retained height	d_{ret} = **3500** mm
Depth of unplanned excavation	d_{ex} = **500** mm
Total retained height	d_s = **4000** mm
Angle of retained slope	β = **0.0** deg
Depth from ground level to tie	d_t = **1000** mm
Depth from GL to top of water table retained side	d_w = **500** mm
Depth from GL to top of water table retaining side	d_{wp} = **4000** mm

Loading

Variable surcharge	$p_{o,Q}$ = **20.0** kN/m²

Soil layer 1

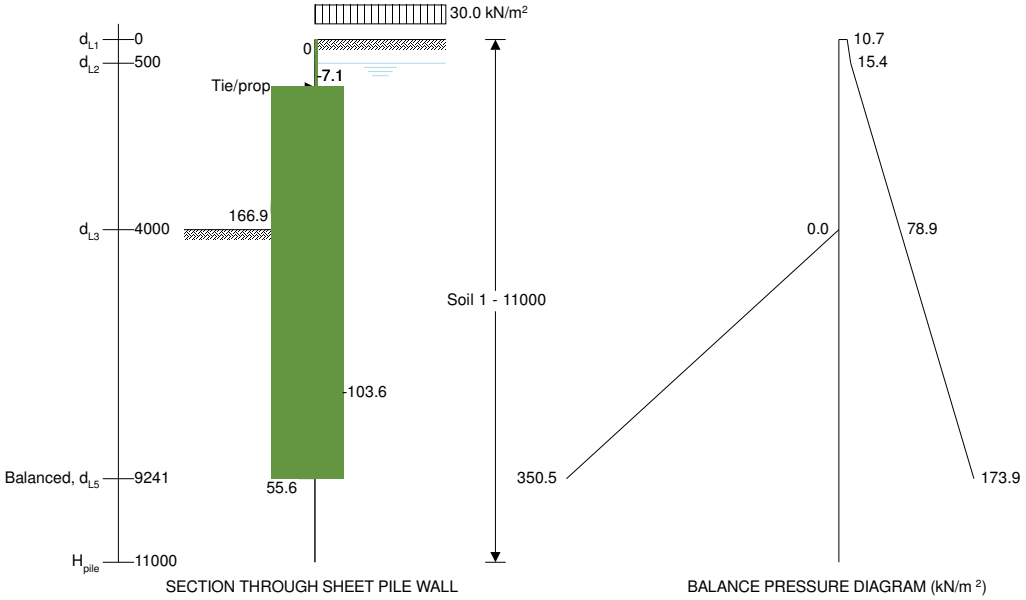
Characteristic shearing resistance angle	ϕ'_{k_s1} = **25.0** deg
Characteristic wall friction angle	δ_{k_s1} = **25.0** deg
Moist density of soil	γ_{m_s1} = **20.0** kN/m³
Characteristic saturated density of retained soil	γ_{s_s1} = **20.0** kN/m³
Height of soil 1	h_1 = **11500** mm

Partial factors on actions - Section A.3.1 - Combination 1

Permanent unfavourable action	γ_G = **1.35**
Permanent favourable action	$\gamma_{G,f}$ = **1.00**
Variable unfavourable action	γ_Q = **1.50**
Angle of shearing resistance	$\gamma_{\phi'}$ = **1.00**
Weight density	γ_γ = **1.00**

Design soil properties - soil 1

Design effective shearing resistance angle	$\phi'_d = \text{Atan}(\tan(\phi'_k) / \gamma_{\phi'})$ = **25.0** deg
Design wall friction angle	$\delta_d = \text{atan}(\tan(\delta_k) / \gamma_{\phi'})$ = **25.0** deg
Design moist density of retained soil	$\gamma_{m.d1} = \gamma_m / \gamma_\gamma$ = **20.0** kN/m³
Design saturated density of retained soil	$\gamma_{s.d1} = \gamma_s / \gamma_\gamma$ = **20.0** kN/m³
Design buoyant density of retained soil	$\gamma_{d.d1} = \gamma_{s.d1} - \gamma_w$ = **10.2** kN/m³
Active pressure using Coulomb theory	$K_{a1} = \sin(\alpha + \phi'_d)^2 / (\sin(\alpha)^2 \times \sin(\alpha - \delta_d) \times (1 + \sqrt{(\sin(\phi'_d + \delta_d) \times \sin(\phi'_d - \beta) / (\sin(\alpha - \delta_d) \times \sin(\alpha + \beta))))^2})$ = **0.355**
Passive pressure using Coulomb theory	$K_{p1} = \sin(90 - \phi'_d)^2 / (\sin(90 + \delta_d) \times [1 - \sqrt{[\sin(\phi'_d + \delta_d) \times \sin(\phi'_d) / (\sin(90 + \delta_d))]]^2})$ = **5.599**



Overburden on active side

Overburden at 0 mm below GL in soil 1 — $OB'_{a11} = p_{o,Q} \times \gamma_Q =$ **30.0** kN/m²

Overburden at 500 mm below GL in soil 1 — $OB'_{a21} = \gamma_G \times \gamma_{m,d1} \times h_{a1} + OB'_{a11} =$ **43.5** kN/m²

Overburden at 4000 mm below GL in soil 1 — $OB'_{a31} = \gamma_G \times \gamma_{d,d1} \times h_{a2} + OB'_{a21} =$ **91.6** kN/m²

Overburden at 9241 mm below GL in soil 1 — $OB'_{a41} = \gamma_G \times \gamma_{d,d1} \times h_{a3} + OB'_{a31} =$ **163.7** kN/m²

Overburden on passive side

Overburden at 4000 mm below GL in soil 1 — $OB'_{p31} = 0$ kN/m² = **0.0** kN/m²

Overburden at 9241 mm below GL in soil 1 — $OB'_{p41} = \gamma_{G,f} \times \gamma_{d,d1} \times h_{p3} + OB'_{p31} =$ **53.4** kN/m²

Pressure on active side

Active at 0 mm below GL in soil 1 — $p'_{a11} = K_{a1} \times OB'_{a11} =$ **10.7** kN/m²

Active at 500 mm below GL in soil 1 — $p'_{a21} = K_{a1} \times OB'_{a21} =$ **15.4** kN/m²

Active at 4000 mm below GL in soil 1 — $p'_{a31} = K_{a1} \times OB'_{a31} + \gamma_G \times \gamma_w \times (d_{L3} - d_w) =$ **78.9** kN/m²

Active at 9241 mm below GL in soil 1 — $p'_{a41} = K_{a1} \times OB'_{a41} + \gamma_G \times \gamma_w \times (d_{L4} - d_w) =$ **173.9** kN/m²

Pressure on passive side

Passive at 4000 mm below GL in soil 1 — $p'_{p31} = K_{p1} \times OB'_{p31} + \gamma_{G,f} \times \gamma_w \times (d_{L3} - \max(d_s, d_w)) =$ **0.0** kN/m²

Passive at 9241 mm below GL in soil 1 — $p'_{p41} = K_{p1} \times OB'_{p41} + \gamma_{G,f} \times \gamma_w \times (d_{L4} - \max(d_s, d_w)) =$ **350.4** kN/m²

Find the force in the tie by taking moments about and above the contraflexure point, where the contraflexure point is assumed to occur at the level when the active pressure equals the passive pressure

Depth to point of contraflexure — $d_{contra} =$ **5619** mm

Sum of active moments about contraflexure point — $\Sigma M_{ac} =$ **642.5** kNm/m

Sum of passive moments about contraflexure point — $\Sigma M_{pc} =$ **47.3** kNm/m

Force in tie — $T = (\Sigma M_{ac} - \Sigma M_{pc}) / (d_{contra} - d_t) =$ **128.9** kN/m

By iteration the depth at which the moments of all the forces are in equilibrium has been determined as 9241 mm as follows:-

Active moment about 9241 mm

Moment level 1 — $M_{a11} = 0.5 \times p'_{a11} \times h_{a1} \times ((H - d_{L2}) + 2/3 \times h_{a1}) =$ **24.2** kNm/m

Moment level 1 — $M_{a12} = 0.5 \times p'_{a21} \times h_{a1} \times ((H - d_{L2}) + 1/3 \times h_{a1}) =$ **34.4** kNm/m

Moment level 2	$M_{a21} = 0.5 \times p'_{a21} \times h_{a2} \times ((H - d_{L3}) + 2/3 \times h_{a2}) =$ **204.7** kNm/m
Moment level 2	$M_{a22} = 0.5 \times p'_{a31} \times h_{a2} \times ((H - d_{L3}) + 1/3 \times h_{a2}) =$ **884.7** kNm/m
Moment level 3	$M_{a31} = 0.5 \times p'_{a31} \times h_{a3} \times ((H - d_{L4}) + 2/3 \times h_{a3}) =$ **722.3** kNm/m
Moment level 3	$M_{a32} = 0.5 \times p'_{a41} \times h_{a3} \times ((H - d_{L4}) + 1/3 \times h_{a3}) =$ **796.1** kNm/m

Passive moment about 9241 mm

Moment level 3	$M_{p31} = 0.5 \times p'_{p31} \times h_{p3} \times ((H - d_{L4}) + 2/3 \times h_{p3}) =$ **0.0** kNm/m
Moment level 3	$M_{p32} = 0.5 \times p'_{p41} \times h_{p3} \times ((H - d_{L4}) + 1/3 \times h_{p3}) =$ **1604.3** kNm/m
Moment about toe for tie/prop	$M_{pt} = T \times (H - d_t) =$ **1062.0** kNm/m

Total moments about 9241 mm

Total active moment	$\Sigma M_a =$ **2666.8** kNm/m
Total passive moment	$\Sigma M_p =$ **2666.8** kNm/m

Required pile length

Length of pile required to balance moments	$H =$ **9241** mm
Depth to point of contraflexure	$d_{contra} =$ **5619** mm
Add 20% below this point	$d_{e\_add} = 1.2 \times (H - d_{contra}) =$ **4347** mm
Minimum required pile length	$H_{total} = d_{contra} + d_{e\_add} =$ **9965** mm

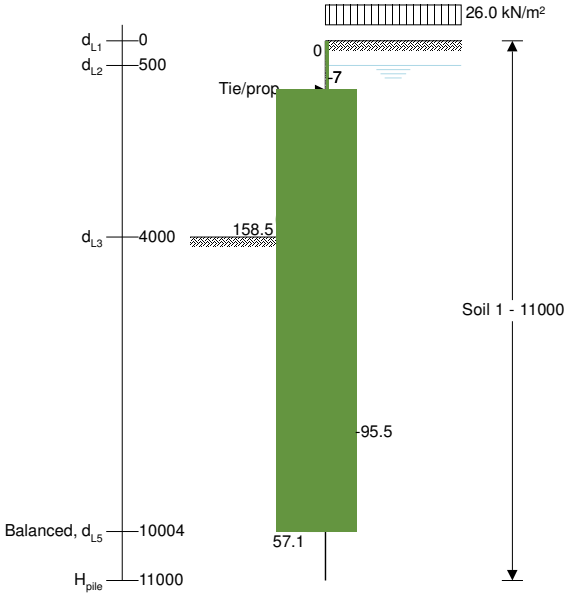
Pass - Provided length of sheet pile greater than minimum required length of pile

Partial factors on actions - Section A.3.1 - Combination 2

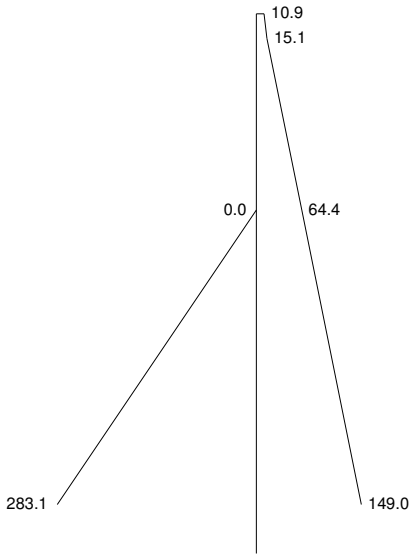
Permanent unfavourable action	$\gamma_G =$ **1.00**
Permanent favourable action	$\gamma_{G,f} =$ **1.00**
Variable unfavourable action	$\gamma_Q =$ **1.30**
Angle of shearing resistance	$\gamma_{\phi'} =$ **1.25**
Weight density	$\gamma_\gamma =$ **1.00**

Design soil properties - soil 1

Design effective shearing resistance angle	$\phi'_d = \text{Atan}(\tan(\phi'_k) / \gamma_{\phi'}) =$ **20.5** deg
Design wall friction angle	$\delta_d = \text{atan}(\tan(\delta_k) / \gamma_{\phi'}) =$ **20.5** deg
Design moist density of retained soil	$\gamma_{m.d1} = \gamma_m / \gamma_\gamma =$ **20.0** kN/m³
Design saturated density of retained soil	$\gamma_{s.d1} = \gamma_s / \gamma_\gamma =$ **20.0** kN/m³
Design buoyant density of retained soil	$\gamma_{d.d1} = \gamma_{s.d1} - \gamma_w =$ **10.2** kN/m³
Active pressure using Coulomb theory	$K_{a1} = \sin(\alpha + \phi'_d)^2 / (\sin(\alpha)^2 \times \sin(\alpha - \delta_d) \times (1 + \sqrt{(\sin(\phi'_d + \delta_d) \times \sin(\phi'_d - \beta) / (\sin(\alpha - \delta_d) \times \sin(\alpha + \beta))))^2}) =$ **0.420**
Passive pressure using Coulomb theory	$K_{p1} = \sin(90 - \phi'_d)^2 / (\sin(90 + \delta_d) \times [1 - \sqrt{[\sin(\phi'_d + \delta_d) \times \sin(\phi'_d) / (\sin(90 + \delta_d))]]^2}) =$ **3.664**



SECTION THROUGH SHEET PILE WALL



BALANCE PRESSURE DIAGRAM (kN/m²)

Overburden on active side

Overburden at 0 mm below GL in soil 1 — $OB'_{a11} = p_{o,Q} \times \gamma_Q =$ **26.0** kN/m²

Overburden at 500 mm below GL in soil 1 — $OB'_{a21} = \gamma_G \times \gamma_{m.d1} \times h_{a1} + OB'_{a11} =$ **36.0** kN/m²

Overburden at 4000 mm below GL in soil 1 — $OB'_{a31} = \gamma_G \times \gamma_{d.d1} \times h_{a2} + OB'_{a21} =$ **71.7** kN/m²

Overburden at 10004 mm below GL in soil 1 — $OB'_{a41} = \gamma_G \times \gamma_{d.d1} \times h_{a3} + OB'_{a31} =$ **132.8** kN/m²

Overburden on passive side

Overburden at 4000 mm below GL in soil 1 — $OB'_{p31} = 0$ kN/m² = **0.0** kN/m²

Overburden at 10004 mm below GL in soil 1 — $OB'_{p41} = \gamma_{G,f} \times \gamma_{d.d1} \times h_{p3} + OB'_{p31} =$ **61.2** kN/m²

Pressure on active side

Active at 0 mm below GL in soil 1 — $p'_{a11} = K_{a1} \times OB'_{a11} =$ **10.9** kN/m²

Active at 500 mm below GL in soil 1 — $p'_{a21} = K_{a1} \times OB'_{a21} =$ **15.1** kN/m²

Active at 4000 mm below GL in soil 1 — $p'_{a31} = K_{a1} \times OB'_{a31} + \gamma_G \times \gamma_w \times (d_{L3} - d_w) =$ **64.4** kN/m²

Active at 10004 mm below GL in soil 1 — $p'_{a41} = K_{a1} \times OB'_{a41} + \gamma_G \times \gamma_w \times (d_{L4} - d_w) =$ **149.0** kN/m²

Pressure on passive side

Passive at 4000 mm below GL in soil 1 — $p'_{p31} = K_{p1} \times OB'_{p31} + \gamma_{G,f} \times \gamma_w \times (d_{L3} - \max(d_s, d_w)) =$ **0.0** kN/m²

Passive at 10004 mm below GL in soil 1 — $p'_{p41} = K_{p1} \times OB'_{p41} + \gamma_{G,f} \times \gamma_w \times (d_{L4} - \max(d_s, d_w)) =$ **283.0** kN/m²

Find the force in the tie by taking moments about and above the contraflexure point, where the contraflexure point is assumed to occur at the level when the active pressure equals the passive pressure

Depth to point of contraflexure — $d_{contra} =$ **5948** mm

Sum of active moments about contraflexure point — $\Sigma M_{ac} =$ **640.9** kNm/m

Sum of passive moments about contraflexure point — $\Sigma M_{pc} =$ **58.1** kNm/m

Force in tie — $T = (\Sigma M_{ac} - \Sigma M_{pc}) / (d_{contra} - d_t) =$ **117.8** kN/m

By iteration the depth at which the moments of all the forces are in equilibrium has been determined as 10004 mm as follows:-

Active moment about 10004 mm

Moment level 1 — $M_{a11} = 0.5 \times p'_{a11} \times h_{a1} \times ((H - d_{L2}) + 2/3 \times h_{a1}) =$ **26.8** kNm/m

Moment level 1	$M_{a12} = 0.5 \times p'_{a21} \times h_{a1} \times ((H - d_{L2}) + 1/3 \times h_{a1}) =$ **36.5** kNm/m
Moment level 2	$M_{a21} = 0.5 \times p'_{a21} \times h_{a2} \times ((H - d_{L3}) + 2/3 \times h_{a2}) =$ **220.4** kNm/m
Moment level 2	$M_{a22} = 0.5 \times p'_{a31} \times h_{a2} \times ((H - d_{L3}) + 1/3 \times h_{a2}) =$ **808.2** kNm/m
Moment level 3	$M_{a31} = 0.5 \times p'_{a31} \times h_{a3} \times ((H - d_{L4}) + 2/3 \times h_{a3}) =$ **773.9** kNm/m
Moment level 3	$M_{a32} = 0.5 \times p'_{a41} \times h_{a3} \times ((H - d_{L4}) + 1/3 \times h_{a3}) =$ **895.1** kNm/m

Passive moment about 10004 mm

Moment level 3	$M_{p31} = 0.5 \times p'_{p31} \times h_{p3} \times ((H - d_{L4}) + 2/3 \times h_{p3}) =$ **0.0** kNm/m
Moment level 3	$M_{p32} = 0.5 \times p'_{p41} \times h_{p3} \times ((H - d_{L4}) + 1/3 \times h_{p3}) =$ **1700.5** kNm/m
Moment about toe for tie/prop	$M_{pt} = T \times (H - d_t) =$ **1060.4** kNm/m

Total moments about 10004 mm

Total active moment	$\Sigma M_a =$ **2761.1** kNm/m
Total passive moment	$\Sigma M_p =$ **2761.2** kNm/m

Required pile length

Length of pile required to balance moments	$H =$ **10004** mm
Depth to point of contraflexure	$d_{contra} =$ **5948** mm
Add 20% below this point	$d_{e\_add} = 1.2 \times (H - d_{contra}) =$ **4867** mm
Minimum required pile length	$H_{total} = d_{contra} + d_{e\_add} =$ **10815** mm

Pass - Provided length of sheet pile greater than minimum required length of pile