8.0 REFERENCE

1. Coduto, D.P. (2001), Foundation Design Principles and Practices, 2'nd Edition, Prentice Hall.

2. Das, B. M. 2011. "Principle of Foundation Engineering.**"** 7**th** Ed., Cengage Learning**,** Stamford, CT: United States.

3. Smoltczyk, U. 2003. "Geotechnical engineering handbook." Ernst and Sohn A Wiley Company.

4. National Engineering Handbook 2007. "Design and Use of Sheet Pile Walls in Stream Restoration and Stabilization Projects." Technical Supplement 14R, Part 654.

5. Bilgin, Ö. and Erten, M. B. 2009. "Analysis of Anchored Sheet Pile Wall Deformations." International Foundation Congress and Equipment Expo (GSP 187), Orlando, Florida, P. 137-144.

6. PLAXIS 2D 2011. "Essential for geotechnical professionals." Tutorial Manual.

7.ArcelorMittal Piling Handbook 2008. "Design of sheet pile walls." 8th Ed., ArcelorMittal Inc., Chicago, IN.

8. Youssef Gomaa Youssef Morsi ,2003. "Berms For Stablizing Earth Retaining Structures

9. Aziz, F. (1999). "Applied analysis in geotechnics" London: E & FN spon.

10.Boweles, J. E. (1988). "Foundation analysis and design", 4th edition NewYork: McGraw-Hill

11. ÁRNI JÓNSSON," Sheet Pile Walls – A space-Saving Avalanche Defence Structure" (2006),ORION Consulting Engineers

APPENDIX A

Finite element model results
(Parameters of the main retaining wall)

1.1 Anchored Sheet Pile Wall Model Results - (4m Improvement wall)

Case 1

Int. Fric.Angle	Wall Hori. Def (mm)	Bending Mom. (kNm)	Anchor Force (kN)	Excavation Depth (m)
22	204.51	190.93	115.6	6.8*
24	32.16	146.62	85.74	6.8*
26	45.17	153.91	97.38	7
28	10.17	117.14	66.38	7
30	7.23	98.98	57.93	7
32	5.83	82.89	52.06	7
34	4.93	71.36	47.37	7
36	4.05	60	42.33	7
38	3.33	50.51	37.75	7

Case 2

Int. Fric.Angle	Wall Hori. Def (mm)	Bending Mom. (kNm)	Anchor Force (kN)	Excavation Depth (m)
22	20.48	139.73	73.1	6.6*
24	22.1	140.13	77.37	7*
26	12.59	124	68.26	7
28	7.92	101.41	57.22	7
30	6.13	85.66	52.03	7
32	4.89	72.14	46.58	7
34	3.94	60.62	41.83	7
36	3.05	49.3	36.78	7
38	2.24	38.18	31.12	7

Case 3

Int. Fric.Angle	Wall Hori. Def (mm)	Bending Mom. (kNm)	Anchor Force (kN)	Excavation Depth (m)
22	37.14	149.88	83.08	6.8*
24	17.6	129.73	69.58	7*
26	11.1	113.84	63.21	7
28	6.91	91.9	54.25	7
30	5.29	78.26	49.21	7
32	4.01	63.4	43.37	7
34	3.14	52.61	38.28	7
36	2.4	42.53	33.59	7
38	1.85	34.61	29.02	7

Case 4

Int. Fric.Angle	Wall Hori. Def (mm)	Bending Mom. (kNm)	Anchor Force (kN)	Excavation Depth (m)
22	31.44	144.39	78.97	6.8*
24	14.23	119.69	63.94	7*
26	9.03	104.01	57.82	7
28	5.84	84.25	50.88	7
30	4.43	71.06	46.06	7
32	3.29	56.71	40.28	7
34	2.46	45.53	34.82	7
36	1.85	36.96	30.46	7
38	1.39	29.92	26.17	7

Case 5

Int. Fric.Angle	Wall Hori. Def (mm)	Bending Mom. (kNm)	Anchor Force (kN)	Excavation Depth (m)
22	52.37	148.59	89.41	6.8*
24	20.62	125.08	71.93	7*
26	7.52	97.52	54.71	7
28	4.85	77.85	47.88	7
30	3.62	63.57	42.9	7
32	2.58	49.9	36.96	7
34	1.9	39.91	31.82	7
36	1.36	31.95	27.09	7
38	0.933	25.31	22.79	7

Case 6

Int. Fric.Angle	Wall Hori. Def (mm)	Bending Mom. (kNm)	Anchor Force (kN)	Excavation Depth (m)
22	41.53	143.53	84.31	6.8*
24	15.27	117.76	64.65	7*
26	6.13	91.99	51.87	7
28	4.15	73.25	45.64	7
30	2.97	57.77	40.09	7
32	2.01	44.27	33.43	7
34	1.39	34.93	28.4	7
36	0.945	27.77	24.16	7
38	0.607	22.48	20.37	7

* soil body collapses in the numerical model

1.2 Anchored Sheet Pile Wall Model Results - (6m Improvement wall)

Case 1

Int. Fric.Angle	Wall Hori. Def (mm)	Bending Mom. (kNm)	Anchor Force (kN)	Excavation Depth (m)
22	204.51	190.93	115.6	6.6*
24	32.16	146.62	85.74	6.8*
26	30.26	149.23	92.49	7.2*
28	18.72	136.33	82.52	7.4*
30	19.07	132.51	87.73	7.6*
32	15.57	120.98	82.37	7.8*
34	8.81	97.26	62.32	7.8*
36	9.36	93.12	64.43	8*
38	8.42	85.03	61.7	8

Case 2

Int. Fric.Angle	Wall Hori. Def (mm)	Bending Mom. (kNm)	Anchor Force (kN)	Excavation Depth (m)
22	42.32	147.96	90.74	6.8*
24	29.47	132.97	83.63	7*
26	19.84	119.23	80.46	7.2*
28	16.18	108.01	78.19	7.4*
30	10.52	90.39	66.3	7.6*
32	8.63	80.28	61.83	7.8*
34	7.48	71.82	57.83	8*
36	6.56	63.79	54.11	8
38	5.02	53.7	44.91	8

Case 4

Int. Fric.Angle	Wall Hori. Def (mm)	Bending Mom. (kNm)	Anchor Force (kN)	Excavation Depth (m)
22	29.55	130.41	79.23	6.8*
24	16.34	110.18	66.94	7*
26	30.7	123.22	91.17	7.6*
28	19.88	109.01	84.14	7.8*
30	13.16	93.85	73.83	8*
32	10.03	79.73	65.92	8
34	6.45	62.47	52.56	8
36	4.39	49.21	40.94	8
38	3.22	39.42	33.83	8

Case 6

Int. Fric.Angle	Wall Hori. Def (mm)	Bending Mom. (kNm)	Anchor Force (kN)	Excavation Depth (m)
22	41.53	143.53	84.31	6.8*
24	15.27	117.76	64.65	6.8*
26	6.13	91.99	51.87	7
28	4.15	73.25	45.64	7
30	2.97	57.77	40.09	7
32	2.01	44.27	33.43	7
34	1.39	34.93	28.4	7
36	0.945	27.77	24.16	7
38	0.607	22.48	20.37	7

* soil body collapses in the numerical model

1.3 Cantilever Sheet Pile Wall Model Results - (6m Improvement wall)

Case 1

Int. Fric.Angle	Wall Hori. Def (mm)	Bending Mom. (kNm)	Excavation Depth (m)
22	297.42	149.57	3.8*
24	198.73	145.7	4*
26	114.81	140.35	4.4*
28	46.59	117.76	4.4*
30	80.66	131.63	4.8*
32	42.99	110.56	4.8*
34	58.46	116.09	5
36	42.3	102.65	5
38	30.26	88.28	5

Case 2

Int. Fric.Angle	Wall Hori. Def (mm)	Bending Mom. (kNm)	Excavation Depth (m)
22	135.34	93.42	4*
24	44.15	77.54	4*
26	104.09	78.15	4.6*
28	66.27	68.72	4.8*
30	36.48	56.81	4.8*
32	45.28	55	5*
34	28.18	44.89	5
36	18.67	38.3	5
38	13.99	33.78	5

Case 3

Int. Fric.Angle	Wall Hori. Def (mm)	Bending Mom. (kNm)	Excavation Depth (m)
22	201.46	96.53	4.2*
24	51.63	78.08	4.2*
26	98.65	77.72	4.6*
28	44.21	63.57	4.8*
30	34.7	55.03	5*
32	29.22	47.99	5
34	18.97	40.48	5
36	13.15	33.31	5
38	9.13	28.22	5

Case 4

Int. Fric.Angle	Wall Hori. Def (mm)	Bending Mom. (kNm)	Excavation Depth (m)
22	106.97	94.29	4.2*
24	130.6	88.04	4.6*
26	37.08	67.98	4.6*
28	46.09	63.92	5*
30	33.52	52.89	5
32	19.23	43.93	5
34	12.63	36.47	5
36	8.29	30.61	5
38	5.85	26.1	5

Case 5

Int. Fric.Angle	Wall Hori. Def (mm)	Bending Mom. (kNm)	Excavation Depth (m)
22	163.37	96.44	4.4*
24	184.38	86.52	4.8*
26	79.01	75.13	5*
28	48.77	64.22	5
30	20.76	49.43	5
32	12.69	41.84	5
34	7.53	34.15	5
36	5.25	29.2	5
38	3.69	25.77	5

Case 6

Int. Fric.Angle	Wall Hori. Def (mm)	Bending Mom. (kNm)	Excavation Depth (m)
22	264.56	100.16	4.4*
24	193.87	89.19	4.8*
26	21.53	67.52	5
28	29	59.58	5
30	14.08	50.44	5
32	7.85	40.47	5
34	4.83	33.73	5
36	3.08	29.34	5
38	1.83	24.83	5

* soil body collapses in the numerical model

1.4 Cantilever Sheet Pile Wall Model Results - (8m Improvement wall)

Case 1

Int. Fric.Angle	Wall Hori. Def (mm)	Bending Mom. (kNm)	Excavation Depth (m)
22	297.42	149.57	3.8*
24	198.73	145.7	4*
26	114.81	140.35	4.4*
28	46.59	117.76	4.4*
30	80.66	131.63	4.8*
32	42.99	110.56	4.8*
34	103.16	132.33	5.4*
36	62.42	114.91	5.4*
38	47.24	102.95	5.4*

Case 2

Int. Fric.Angle	Wall Hori. Def (mm)	Bending Mom. (kNm)	Excavation Depth (m)
22	134.63	84.85	4.4*
24	227.7	72.55	5*
26	60.23	71.44	4.8*
28	65.05	67.06	5.2*
30	22.6	55.33	4.8*
32	60.96	48.87	5*
34	33.15	47.36	5.6*
36	18.21	38.07	5.4*
38	14.37	33.14	5.4*

Case 4

Int. Fric.Angle	Wall Hori. Def (mm)	Bending Mom. (kNm)	Excavation Depth (m)
22	37.03	87.27	4*
24	39.67	75.19	4.4*
26	54.56	68.36	5*
28	78.78	59.74	5.4*
30	32.85	50.16	5.4*
32	27.83	42.44	5.6*
34	39	36.99	6
36	27.87	31.56	6
38	26.04	27.45	6

Case 6

Int. Fric.Angle	Wall Hori. Def (mm)	Bending Mom. (kNm)	Excavation Depth (m)
22	251.13	89.66	5*
24	33.69	74.37	4.6*
26	39.32	64.7	5.2*
28	89.68	56.58	6*
30	51.6	53.51	6*
32	33.61	45.13	6
34	20.72	36.96	6
36	13.97	31.85	6
38	9.71	26.93	6

* soil body collapses in the numerical model

APPENDIX B

Finite element model results
(Parameters of the improvement wall)

2.1 Anchored sheet pile wall - Parameters of 4m improvement wall

Case 2

Int. Fric.Angle	Wall Hori. Def (mm)	Bending Mom. (kNm)	Retaining Height (m)
22	42.56	4.84	6.6
24	56.61	6.65	7
26	35.09	7.39	7
28	17.37	7.94	7
30	11.89	8.97	7
32	8.71	9.94	7
34	6.62	10.66	7
36	4.93	11.24	7
38	3.59	11.94	7

Case 3

Int. Fric.Angle	Wall Hori. Def (mm)	Bending Mom. (kNm)	Retaining Height (m)
22	81.85	5.77	6.8
24	50.96	6.65	7
26	32.37	7.62	7
28	16.23	8.51	7
30	11.01	9.72	7
32	7.83	10.54	7
34	5.8	11.01	7
36	4.25	11.05	7
38	3.19	11.08	7

Case 4

Int. Fric.Angle	Wall Hori. Def (mm)	Bending Mom. (kNm)	Excavation Depth
22	87.46	6.56	6.8
24	44.18	6.68	7
26	32.37	7.62	7
28	14.57	8.68	7
30	10.59	9.43	7
32	7.61	9.98	7
34	4.89	10.43	7
36	3.58	10.41	7
38	2.61	10.63	7

Case 5

Int. Fric.Angle	Wall Hori. Def (mm)	Bending Mom. (kNm)	Excavation Depth
22	163.84	7.46	6.8
24	90.61	8.44	7
26	24.36	8.26	7
28	12.63	8.7	7
30	8.3	9.09	7
32	5.52	9.14	7
34	3.91	9.19	7
36	2.82	9.34	7
38	1.93	9.71	7

Case 6

Int. Fric.Angle	Wall Hori. Def (mm)	Bending Mom. (kNm)	Excavation Depth
22	159.14	7.93	7
24	79.73	9.15	7
26	20.89	8.51	7
28	11.46	8.71	7
30	7.26	8.91	7
32	4.71	8.84	7
34	3.27	8.61	7
36	2.18	8.58	7
38	1.43	8.67	7

* soil body collapses in the numerical model

2.2 Anchored sheet pile wall - Parameters of 6m improvement wall

Case 2

Int. Fric.Angle	Wall Hori. Def (mm)	Bending Mom. (kNm)	Excavation Depth
22	72.82	18.81	6.6*
24	53.4	19.64	7*
26	37.3	20.43	7.2*
28	30.33	21.13	7.4*
30	17.69	21.91	7.6*
32	14.2	22.13	7.8*
34	12.2	21.68	8*
36	10.72	20.85	8
38	7.52	21.5	8

Case 4

Int. Fric.Angle	Wall Hori. Def (mm)	Bending Mom. (kNm)	Excavation Depth
22	49.43	22.98	6.8*
24	29.85	22.05	7*
26	62.01	23.97	7.6*
28	42.93	22.53	7.8*
30	26.83	21.71	8*
32	20.15	21.79	8
34	11.54	22.61	8
36	7.29	22.53	8
38	5.14	21.26	8

Case 6

Int. Fric.Angle	Wall Hori. Def (mm)	Bending Mom. (kNm)	Excavation Depth
22	149.82	25.66	7.2*
24	176.82	24.87	7.6*
26	56.71	24.39	7.8*
28	19.5	25.67	7.8*
30	21.1	25.27	8
32	10.26	25.52	8
34	6.39	23.7	8
36	4.48	21.37	8
38	3.32	18.99	8

* soil body collapses in the numerical model

2.3 Cantilever sheet pile wall - Parameters of 6m improvement wall

Case 2

Int. Fric.Angle	Wall Hori. Def (mm)	Bending Mom. (kNm)	Excavation Depth (m)
22	83.14	43.36	4*
24	26.5	32.78	4*
26	65.1	55.88	4.6*
28	41.21	54.95	4.8*
30	22.26	48.14	4.8*
32	27.91	55.83	5
34	17.01	47.71	5
36	10.97	40.79	5
38	8.03	36.02	5

Case 3

Int. Fric.Angle	Wall Hori. Def (mm)	Bending Mom. (kNm)	Excavation Depth (m)
22	118.98	47.25	4.2*
24	30.58	36.59	4.2*
26	60.44	52.31	4.6*
28	26.88	47.64	4.8*
30	21.18	46.97	5*
32	17.83	46.9	5
34	11.27	40.45	5
36	7.77	34.51	5
38	5.36	28.77	5

Case 4

Int. Fric.Angle	Wall Hori. Def (mm)	Bending Mom. (kNm)	Excavation Depth (m)
22	58.81	38.75	4.2*
24	75.6	45.46	4.6*
26	22.1	39.79	4.6*
28	28.28	47.61	5*
30	20.89	46.45	5
32	11.77	40.1	5
34	7.7	33.73	5
36	5.05	27.57	5
38	3.57	23.11	5

Case 5

Int. Fric.Angle	Wall Hori. Def (mm)	Bending Mom. (kNm)	Excavation Depth (m)
22	86.61	42.89	4.4*
24	106.6	47.52	4.8*
26	47.27	46.83	5*
28	29.53	45.59	5
30	12.8	38.05	5
32	7.77	32.35	5
34	4.71	25.92	5
36	3.3	21.5	5
38	2.28	17.74	5

Case 6

Int. Fric.Angle	Wall Hori. Def (mm)	Bending Mom. (kNm)	Excavation Depth (m)
22	137.06	43.96	4.4*
24	109.92	45.08	4.8*
26	15.69	51.64	5
28	17.56	38.34	5
30	8.44	31.54	5
32	4.89	25.1	5
34	3.05	19.96	5
36	1.97	15.95	5
38	1.24	12.64	5

* soil body collapses in the numerical model

2.4 Cantilever sheet pile wall - Parameters of 8m improvement wall

Case 2

Int. Fric.Angle	Wall Hori. Def (mm)	Bending Mom. (kNm)	Excavation Depth (m)
22	76.73	126.55	4.4*
24	131.69	179.83	5*
26	35.78	98.92	4.8*
28	39.13	114.91	5.2*
30	13.28	54.12	4.6*
32	12.15	53.35	5*
34	20.26	80.58	5.6*
36	10.8	51.68	5.4*
38	8.39	43.81	5.4*

Case 4

Int. Fric.Angle	Wall Hori. Def (mm)	Bending Mom. (kNm)	Excavation Depth (m)
22	18.59	39.43	4*
24	21.66	53.89	4.6*
26	30.66	81.77	5*
28	48.07	119.06	5.6*
30	20.72	75.31	5.4*
32	17.8	70.28	5.6*
34	25.19	87.12	6
36	18.05	70.89	6
38	12.53	55.66	6

Case 6

Int. Fric.Angle	Wall Hori. Def (mm)	Bending Mom. (kNm)	Excavation Depth (m)
22	114	118.13	5*
24	18.18	48.52	4.6*
26	22.8	66.52	5.2*
28	52.29	109.98	6*
30	30	87.06	6*
32	20.15	70.01	6
34	12.65	52.57	6
36	8.56	41.1	6
38	6.07	32.91	6

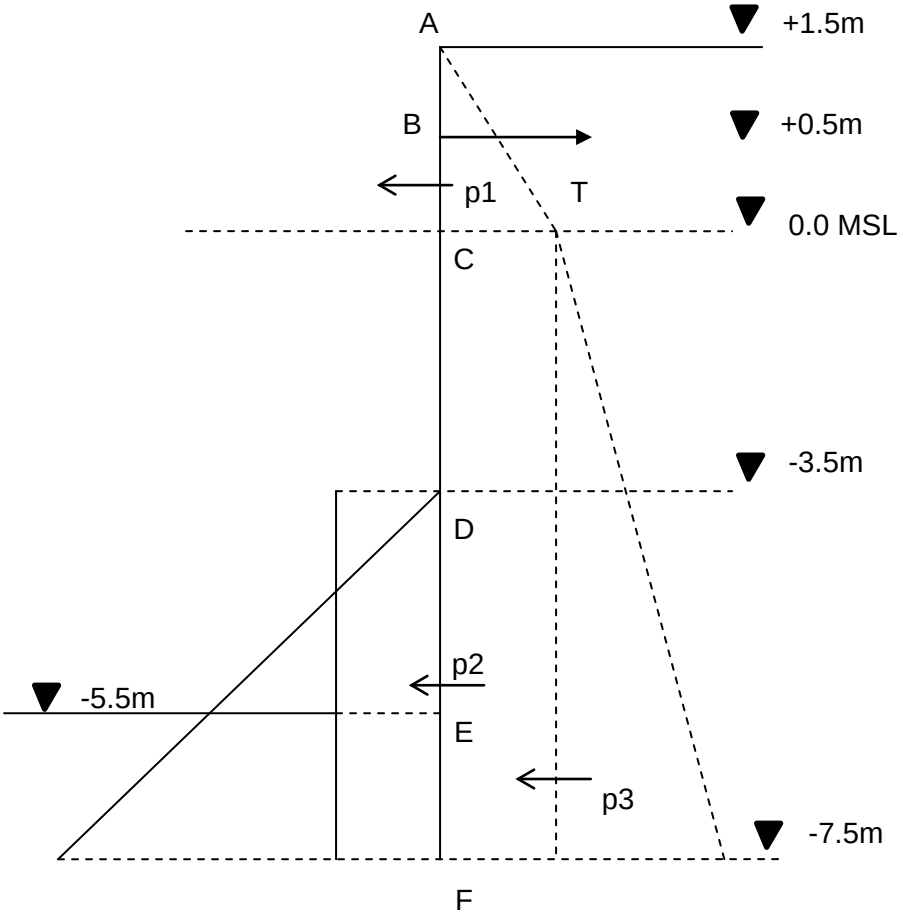
* soil body collapses in the numerical model

APPENDIX C

Sample Calculation

REF	CALCULATION	OUTPUT

Anchored Sheet Pile Wall



<u>Active side</u>

Ka=1/3

Kp=3

σ_A = 0kN/m

$\sigma_C = k_a \gamma Z$
=1/3 × 17 × 1.5
=8.5kN/m^2

$\sigma_F = k_a[\gamma z_1 + (\gamma - \gamma_w) z_2]$
= 8.5+1/3 x 9 x 7.5
= 19kN/m^2

P_1=1/2 x 8.5 x 1.5

=6.375kN

P_2=8.5 x 7.5

=63.75kN

P_3=1/2 x7.5 x 22.5

=84.375kN

<u>Passive side</u>

$\sigma_{F,ult}$ = kp x γ x z

= 3 x 9 x 4

= 108kN/m^2

$Fp_{,ult}$ =1/2 x 108 x 4

= 216 kN

↺ F , take moments around point F

0 = P_1 * 0.5 + P_2 * 4.75 + P3 x 6 - Fp * 7.17

Fp, = 113.28 kN

FOS = 216/113.28 =1.91

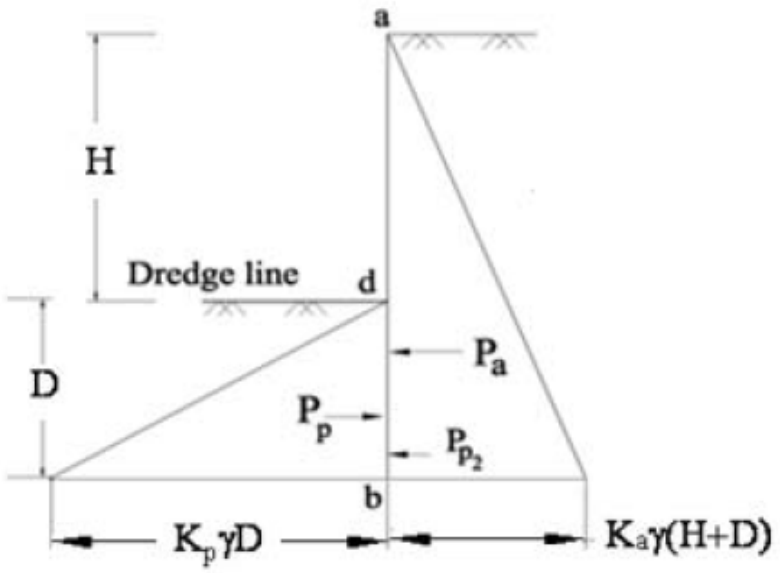
→ Horizontal force equilibrium

P_1+ P_2 + P_3 = Fp + T

T = 41.22 kN

Anchor Force = 41.22 kN

Improvement Sheet Pile wall - Anchored Sheet Pile Structure



H = 3.0 m

φ = 30

γ = 19 kN/m^3

Taking moments about b;

$P_p \times \frac{D}{3} - P_a \times \frac{(H+D)}{3} = 0$

$$K_p\gamma_s D^3 - K_a\gamma_s(H+D)^3 = 0$$

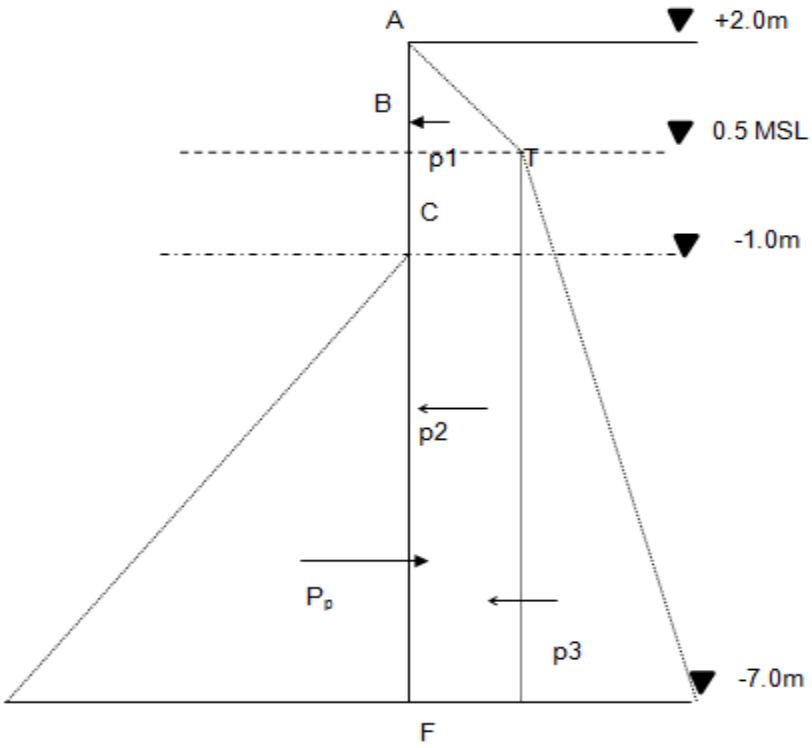
D = 1.85 m

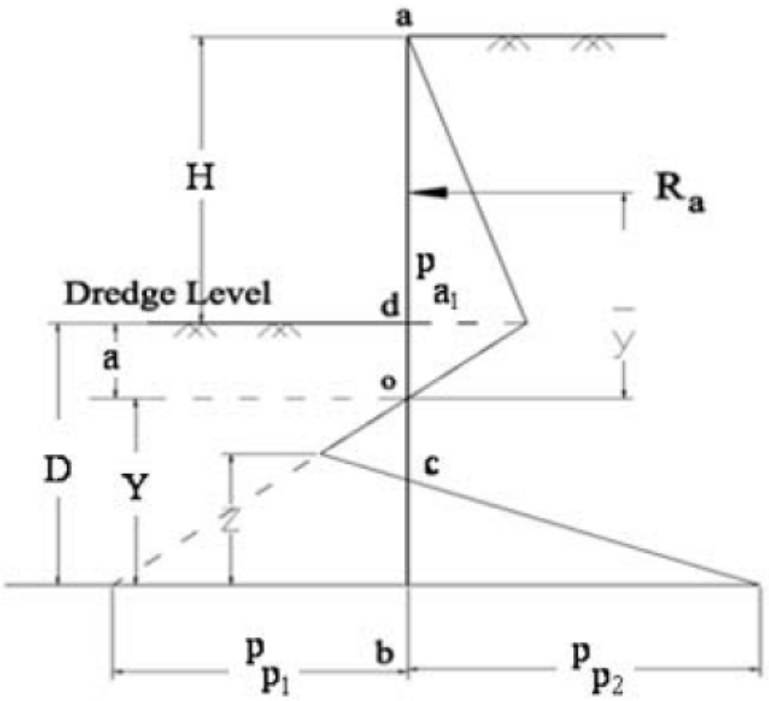
D_{actual} = 2.0 m

D_{actual} = D_{design} x 8%

(20% - 40% recommended)

Cantilever Sheet Pile Wall





At point o ;

$K_p \gamma a - (P_{a1} + K_a \gamma a) = 0$

a = 0.54 m

$P_{p1} = (K_p - K_a) \gamma Y$

$P_{p2} = K_p \gamma (H + a + Y) - Ka \gamma (a + Y)$

From the pressure diagram ;

$\bar{Y}$ = 1. 44 m
Ra = 26.01 kN

$\Sigma H = 0$

Ra + 1/2 (Pp1 + Pp2) Z - 1/2 Pp1 Y = 0

taking moments about base b ; $\Sigma M = 0$

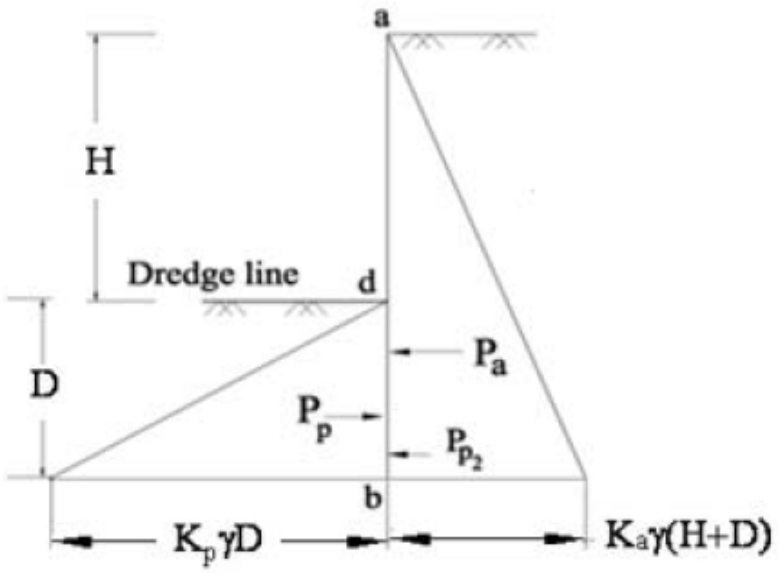
$Ra (\bar{Y} + Y) + 1/2 (Pp1 + Pp2) Z. \frac{Z}{3} - 1/2 Pp1 Y. \frac{Y}{3} = 0$

Y = 4.43 m
D = Y + a
D = 4.97 ~ 5 m

D design = D + D x 20%

= 6.0 m

Improvement Sheet Pile wall - Cantilever Sheet Pile Structure



H = 2.0 m

φ = 30

γ = 19 kN/m^3

Taking moments about b;

$P_p \times \frac{D}{3} - P_a \times \frac{(H+D)}{3} = 0$

$$K_p\gamma_s D^3 - K_a\gamma_s(H+D)^3 = 0$$

D = 1.85 m

D_{actual} = 3.0 m

D_{actual} = D_{design} x 62%

(20% - 40% recommended)