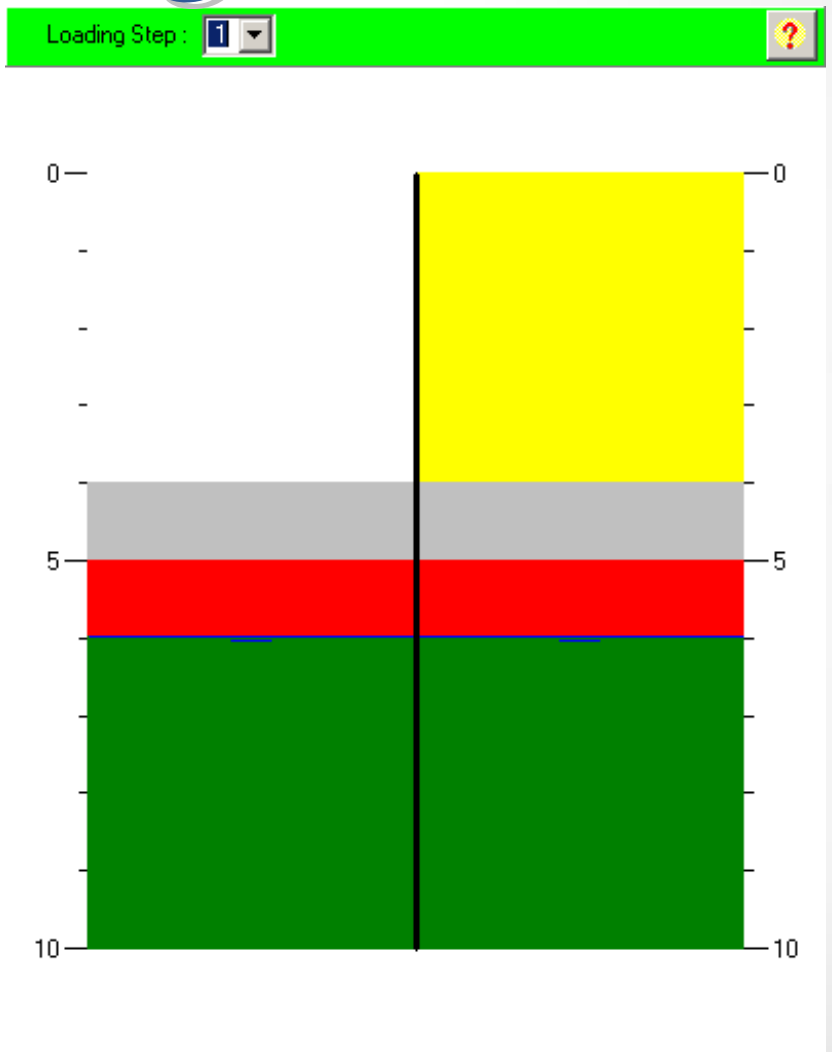
ENCE 4610
Foundation Analysis and Design

Lecture 10
Retaining Walls
Sheet Piling: Overview and Cantilever Walls

Overview of Sheet Piling as a Retaining Wall

- Sheet piling is a structural "in-situ" type of retaining wall
  - Does not rely on its mass to retain the soil, as opposed to a gravity wall
  - In-situ walls rely on their flexural strength to retain soil, supported either by their own penetration into the soil or by an anchoring system
  - Other types of structural in-situ walls
    - Soldier pile walls – use H-beams to hold timber or concrete lagging to retain soil on a temporary or permanent basis
    - Slurry walls – bentonite slurry is injected into a trench after which reinforcement and concrete are placed into the trench, forming a wall

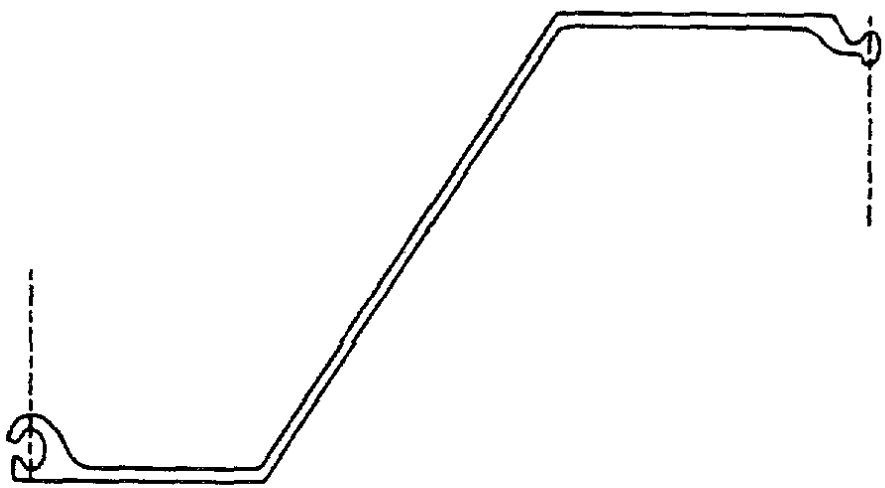


Materials for Sheet Piling

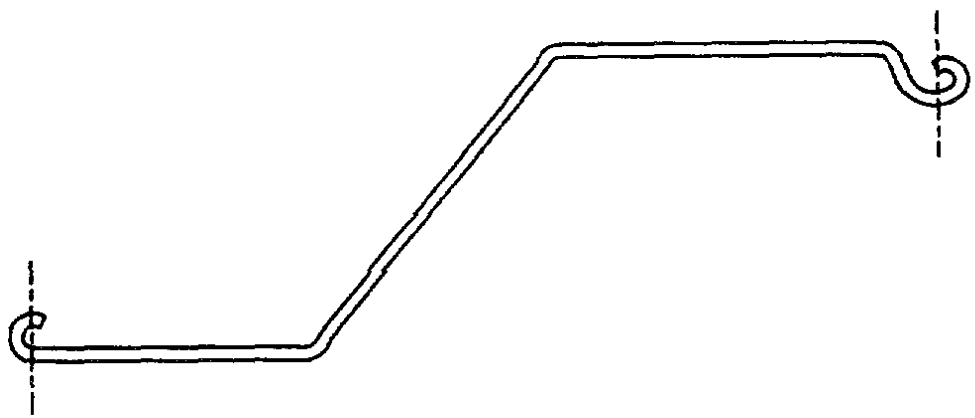
- Steel
  - Cold formed
  - Hot rolled
- Aluminium
  - Extruded
- Vinyl
  - Extruded
- Fibreglass
  - Pultruded
- Concrete
- Wood

Steel Sheet Piles

- Cold formed
  - Form rolled cold from steel plate
  - Common with lighter sheet pile profiles
  - Interlocks more prone to breakage
- Hot rolled
  - Panel and interlocks rolled in one operation
  - “Traditional” form of steel sheet piling



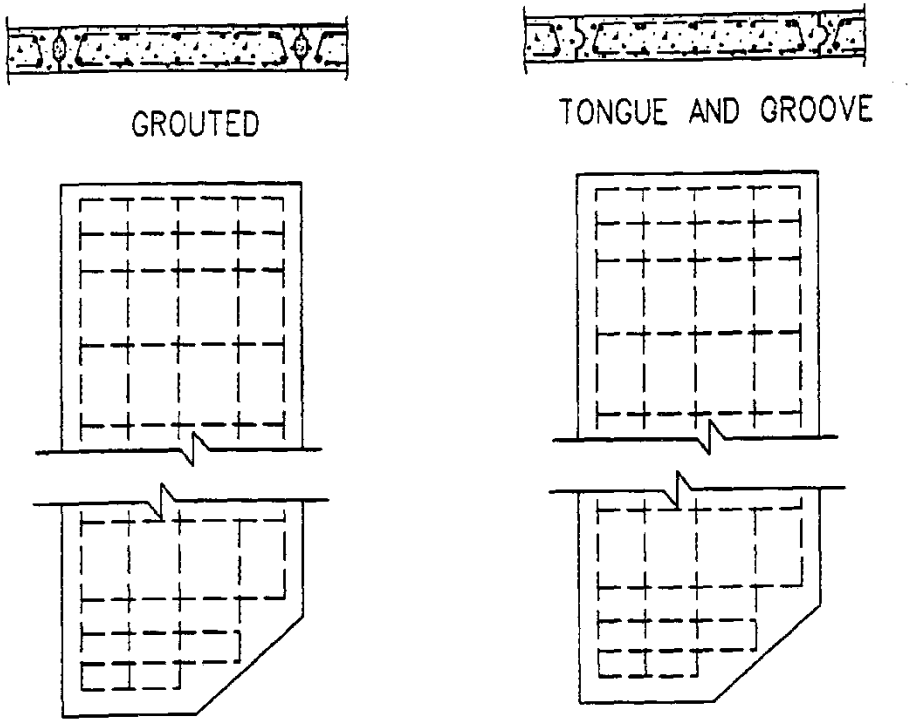
a. Hot-rolled Z-section

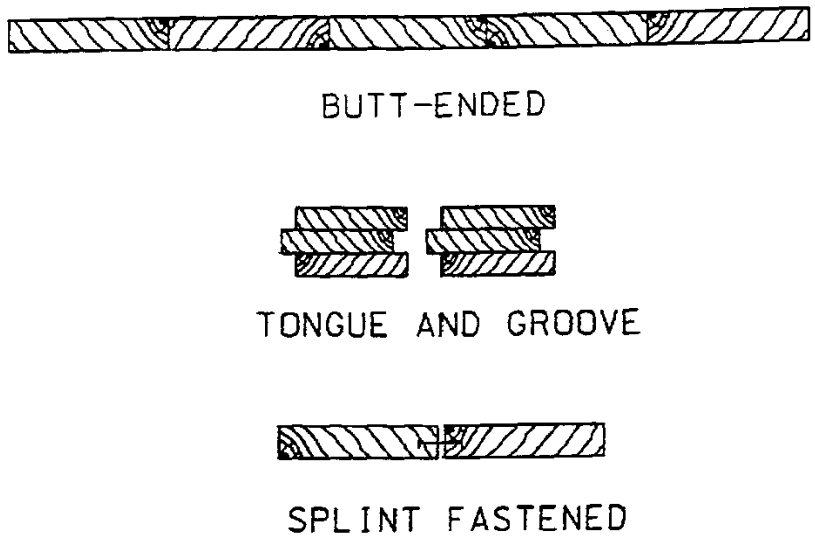


b. Cold-rolled Z-section

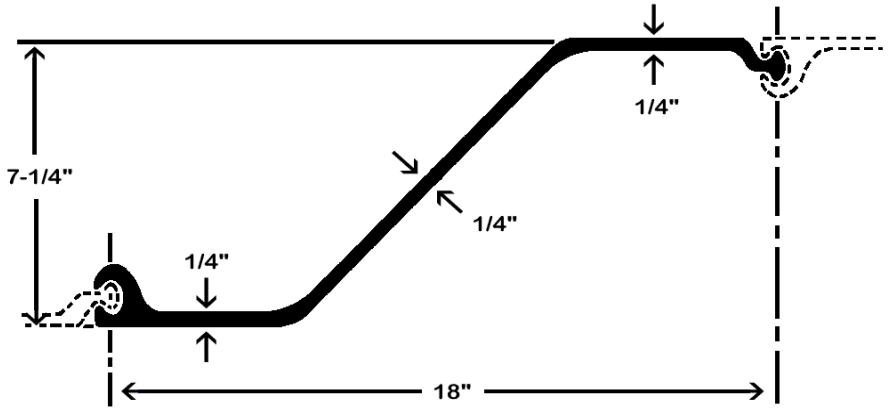
Concrete and Wood Sheeting

- Concrete Sheeting
- Wood Sheeting



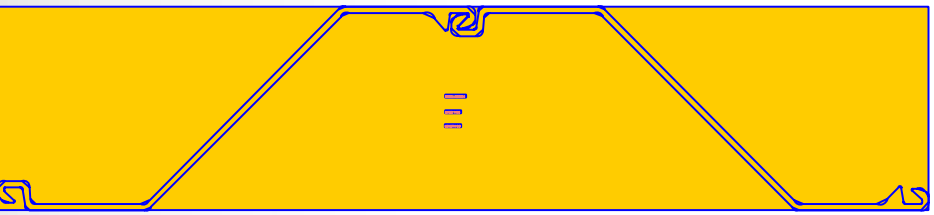


Aluminium, Vinyl and Fibreglass Sheeting



- Made for lightweight and light load applications
- Common substitute for wood or concrete walls
- Require special handling in setting and driving
- Vinyl sheets can be obtained in various colours, but is subject to long term creep

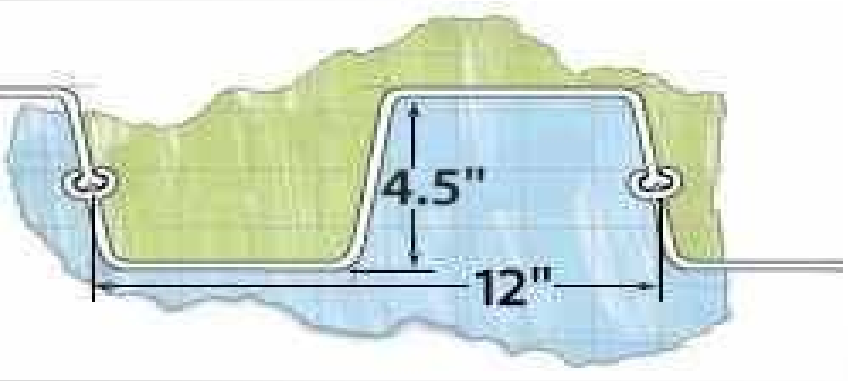
Sections of Sheet Piling



- Z-shaped sheeting
  - Popular in north America
  - Usually drive two at a time with split clamp
  - Wall stiffness developed with each sheet without assumed assistance from the interlocks
- U-shaped sheeting (Larssen, etc.)
  - Very popular in Europe
  - Usually driven one at a time
  - Wall stiffness developed with two sheets and load transferred using the interlocks (European practice; U.S. practice does not assume this load transfer)

Sections of Sheet Piling

- Arched shaped
  - Used for shallower wall construction
  - Used in cold formed steel and aluminium sheeting
- Flat-web sheeting
  - Almost exclusively used for cellular cofferdams
  - Main stress is tensile through the web and interlocks
  - Can be driven singly or two at a time



Transitional Sections and Interlock Styles

- Transitional Sections

c. Fabricated corners

d. Rolled corners

Ball and Socket (BS)

Double Jaw (DJ)

Single Jaw (SJ)

Double Hook (DH)

Thumb and Finger - three point contact (TF)

Thumb and Finger - one point contact (TFX)

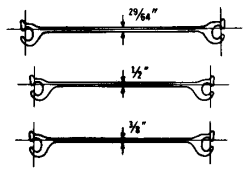
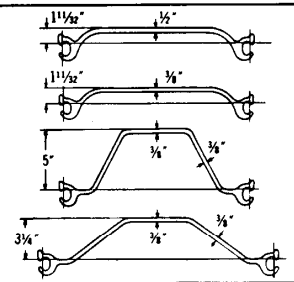
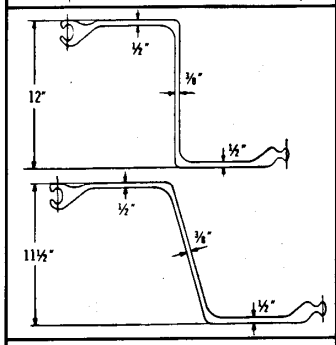
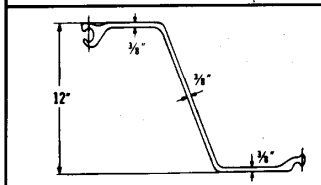
Hook and Grip (HG)

- Interlock Styles
  - Hot rolled and extruded sections
    - Ball and socket
    - Single or double jaw
    - Double hook
    - Thumb and finger
      - One point contact
      - Three point contact
  - Cold formed sections
    - Hook and grip

Specifications for Steel Sheet Piling (USS)

Steel Grade	Allowable Stress, ksi	Allowable Stress, MPa
ASTM A 328	25	172
ASTM A 572 Gr. 45	29	200
ASTM A 572 Gr. 50	32	220
ASTM A 572 Gr. 55	35	241
ASTM A 690	32	220

Steel Sheet Piling Sections

Profile	Section Index		District Rolled	Driving Distance per Pile	Weight Per Foot	Weight Per Square Foot of Wall	Web Thickness	Section Modulus Per Pile	Section Modulus Per Foot of Wall	Area Per Pile	Moment of Inertia Per Pile	Moment of Inertia Per Foot of Wall
				In.	Lbs.	Lbs.	In.	In.³	In.³	In.²	In.⁴	In.⁴
	Interlock with Each Other	PSX32	H.	16½	44.0	32.0	29/64	3.3	2.4	12.94	5.1	3.7
		PS32*	H.S.	15	40.0	32.0	½	2.4	1.9	11.77	3.6	2.9
		PS28	H.S.	15	35.0	28.0	⅜	2.4	1.9	10.30	3.5	2.8
	Interlock with Each Other	PSA28*	H.	16	37.3	28.0	½	3.3	2.5	10.98	6.0	4.5
		PSA23	H.S.	16	30.7	23.0	⅜	3.2	2.4	8.99	5.5	4.1
		PDA27	H.S.	16	36.0	27.0	⅜	14.3	10.7	10.59	53.0	39.8
		PMA22	H.S.	19⅝	36.0	22.0	⅜	8.8	5.4	10.59	22.4	13.7
	Interlock with Each Other and with PSA23 or PSA28	PZ38	H.	18	57.0	38.0	⅜	70.2	46.8	16.77	421.2	280.8
		PZ32	H.	21	56.0	32.0	⅜	67.0	38.3	16.47	385.7	220.4
	Interlocks with Itself and with PSA23 or PSA28	PZ27	H.	18	40.5	27.0	⅜	45.3	30.2	11.91	276.3	184.2

*Sections PS32 and PSA28 are infrequently rolled and we do not advise their use in a design unless an adequate tonnage can be ordered at one time to assure a minimum rolling.

Complete data regarding these sections will be found in a separate publication entitled "USS Steel Sheet Piling."

H—Homestead, Pa. (Pittsburgh District)
S—South Chicago (Chicago District)

Suggested Allowable Design Stresses—Sheet Piling

Steel Brand or Grade	Minimum Yield Point, psi	Allowable Design Stress, psi*
USS-EX-TEN 55 (ASTM A572 GR 55)	55,000	35,000
USS EX-TEN 50 (ASTM A572 GR 50)	50,000	32,000
USS MARINER STEEL	50,000	32,000
USS EX-TEN 45 (ASTM A572 GR 45)	45,000	29,000
Regular Carbon Grade (ASTM A 328)	38,500	25,000

*Based on 65% of minimum yield point. Some increase for temporary overstresses generally permissible.

PZ/PS Sections (Skyline)

PZ/PS

PZ/PS Hot Rolled Steel Sheet Piling

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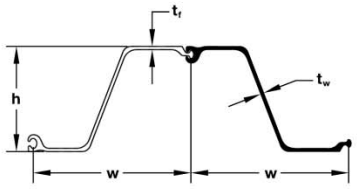
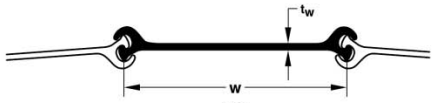


PZ

SECTION	Width (w) in (mm)	Height (h) in (mm)	THICKNESS Flange (t_f) in (mm)	THICKNESS Wall (t_w) in (mm)	Cross Sectional Area in²/ft (cm²/m)	WEIGHT Pile lb/ft (kg/m)	WEIGHT Wall lb/ft² (kg/m²)	SECTION MODULUS Elastic in³/ft (cm³/m)	SECTION MODULUS Plastic in³/ft (cm³/m)	Moment of Inertia in⁴/ft (cm⁴/m)	COATING AREA Both Sides ft²/ft of single (m²/m)	COATING AREA Wall Surface ft²/ft² of wall (m²/m²)
PZ 22	22.0 559	9.0 229	0.375 9.50	0.375 9.50	6.47 136.9	40.3 60.0	22.0 107.4	18.1 973	21.79 1171.4	84.38 11500	4.48 1.37	1.22 1.22
PZ 27	18.0 457	12.0 305	0.375 9.50	0.375 9.50	7.94 168.1	40.5 60.3	27.0 131.8	30.2 1620	36.49 1061.9	184.20 25200	4.48 1.37	1.49 1.49
PZ 35	22.6 575	14.9 378	0.600 15.21	0.500 12.67	10.29 217.8	66.0 98.2	35.0 170.9	48.5 2608	57.17 3073.5	361.22 49300	5.37 1.64	1.42 1.42
PZ 40	19.7 500	16.1 409	0.600 15.21	0.500 12.67	11.77 249.1	65.6 97.6	40.0 195.3	60.7 3263	71.92 3866.7	490.85 67000	5.37 1.64	1.64 1.64



PS

SECTION	Width (w) in (mm)	Web (t_w) in (mm)	Maximum Interlock Strength k/in (kN/m)	Minimum Cell Diameter* ft (m)	Cross Sectional Area in²/ft (cm²/m)	WEIGHT Pile lb/ft (kg/m)	WEIGHT Wall lb/ft² (kg/m²)	Elastic Section Modulus in³/sheet (cm³/sheet)	Moment of Inertia in⁴/sheet (cm⁴/sheet)	COATING AREA Both Sides ft²/ft of single (m²/m)	COATING AREA Wall Surface ft²/ft² of wall (m²/m²)
PS 27.5	19.69 500	0.4 10.2	24 4800	30 9.14	8.09 171.2	45.1 67.1	27.5 134.3	3.3 54	5.3 221	3.65 1.11	1.11 1.11
PS 31	19.69 500	0.5 12.7	24 4800	30 9.14	9.12 193.0	50.9 75.7	31.0 151.4	3.3 54	5.3 221	3.65 1.11	1.11 1.11

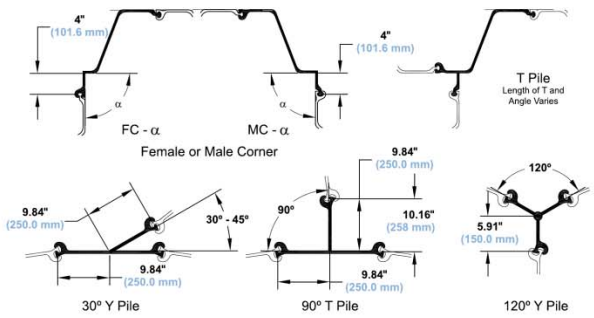
* Minimum cell diameter cannot be guaranteed for piles over 65 feet (19.81 m) in length.
* Minimum cell diameter cannot be guaranteed if piles are spliced.
* 58 Piles are needed to make a 30 foot diameter cell.

PZ/PS

PZ/PS Hot Rolled Steel Sheet Piling

Available Steel Grades							
PZ's			PS's				
ASTM	YIELD STRENGTH (ksi)	YIELD STRENGTH (MPa)	ASTM	YIELD STRENGTH (ksi)	YIELD STRENGTH (MPa)	INTERLOCK STRENGTH (k/in)	INTERLOCK STRENGTH (kN/m)
A 328	39	270	A 328	39	270	16	2800
A 572 Grade 50	50	345	A 572 Grade 50	50	345	20	3500
A 572 Grade 60	60	415	A 572 Grade 60	60	415	24	4200
A 572 Grade 65	65	450	A 572 Grade 65	65	450	24	4200
A 588	50	345	A 588	50	345	20	3500
A 690	50	345	A 690	50	345	20	3500

Corner and Junction Piles



Delivery Conditions & Tolerances

	ASTM A 6	
Mass	± 2.5%	
Length	+ 5 inches	– 0 inches

Maximum Rolled Lengths*

PZ	85 feet for singles, 70 feet for pairs	(25.9 m, 21.3 m)
PS	65 feet	(19.8 m)

* Longer lengths may be possible upon request.

Technical Hotline: 1-866-875-9546 / engineering@skylinesteel.com www.skylinesteel.com

SKZ/SCZ Sections (Skyline)

SKZ/SCZ

SKZ/SCZ Cold Formed Steel Sheet Piling

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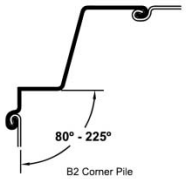
SECTION	Width (w) in (mm)	Height (h) in (mm)	Thickness (t) in (mm)	Cross Sectional Area in²/ft (cm²/m)	WEIGHT Pile lb/ft (kg/m)	WEIGHT Wall lb/ft² (kg/m²)	SECTION MODULUS Elastic in³/ft (cm³/m)	SECTION MODULUS Plastic in³/ft (cm³/m)	Moment of Inertia in⁴/ft (cm⁴/m)	COATING AREA Both Sides ft²/ft (m²/m)	COATING AREA Coating Area ft²/ft² (m²/m²)
SKZ 20	28.50 723.9	16.00 406.4	0.315 8.0	6.00 136.20	48.24 71.79	20.31 99.17	31.69 1704	36.66 1970.97	253.51 34618	7.60 2.32	1.60 1.60
SKZ 22	28.50 723.9	16.00 406.4	0.335 8.5	6.30 145.40	51.30 76.34	21.60 105.46	33.43 1797	38.94 2093.55	267.40 36515	7.60 2.32	1.60 1.60
SKZ 23	28.50 723.9	16.00 406.4	0.354 9.0	6.70 162.50	54.20 80.66	22.82 111.42	35.61 1915	41.12 2210.75	284.90 38905	7.60 2.32	1.60 1.60
SKZ 24	28.50 723.9	16.00 406.4	0.375 9.5	7.10 179.50	57.43 85.47	24.18 118.06	37.73 2028	43.52 2339.78	301.80 41213	7.60 2.32	1.60 1.60
SKZ 25	28.50 723.9	16.00 406.4	0.399 10.1	7.60 188.00	61.10 90.93	25.73 125.61	40.14 2158	46.24 2486.02	321.12 43851	7.60 2.32	1.60 1.60
SCZ 14	28.50 723.9	10.00 254.0	0.250 6.4	4.18 88.48	33.81 50.31	14.23 69.50	14.36 772	16.32 877.4	71.82 9808	6.10 1.86	1.28 1.28
SCZ 16	28.50 723.9	10.00 254.0	0.276 7.0	4.62 97.79	37.37 55.61	15.73 76.82	15.75 847	17.97 965.9	78.73 10751	6.10 1.86	1.28 1.28
SCZ 17	29.95 760.8	10.13 257.3	0.315 8.0	5.16 109.22	43.86 65.27	17.57 85.79	16.86 906	19.57 1051.9	88.77 12122	6.32 1.93	1.27 1.27
SCZ 18	29.95 760.8	10.13 257.3	0.335 8.5	5.49 116.21	46.67 69.45	18.70 91.28	17.86 960	20.85 1121.0	90.48 12356	6.32 1.93	1.27 1.27
SCZ 19	29.95 760.8	10.13 257.3	0.354 9.0	5.80 122.77	49.30 73.37	19.75 96.43	18.74 1008	22.06 1186.0	94.92 12962	6.32 1.93	1.27 1.27
SCZ 21	29.95 760.8	10.13 257.3	0.375 9.5	6.14 129.96	52.19 77.67	20.91 102.10	19.85 1067	23.26 1250.5	100.55 13731	6.32 1.93	1.27 1.27
SCZ 22	24.02 610.0	13.39 340.0	0.315 8.0	6.43 136.20	43.81 65.19	21.89 106.90	29.76 1600	33.75 1814.8	199.19 27200	5.91 1.80	1.48 1.48
SCZ 23	24.02 610.0	13.39 340.0	0.335 8.5	6.87 145.40	46.84 69.70	23.35 114.00	31.62 1700	36.08 1939.9	223.63 28900	5.91 1.80	1.48 1.48
SCZ 25	24.02 610.0	13.39 340.0	0.354 9.0	7.27 153.95	49.60 73.80	24.78 121.00	33.48 1800	38.13 2050.2	224.08 30600	5.91 1.80	1.48 1.48
SCZ 26	24.02 610.0	13.39 340.0	0.375 9.5	7.68 162.50	52.28 77.80	26.22 128.00	35.34 1900	40.28 2165.8	236.53 32300	5.91 1.80	1.48 1.48
SCZ 29	24.02 610.0	13.39 340.0	0.413 10.5	8.48 179.50	57.92 86.20	28.88 141.00	39.06 2100	44.49 2392.2	261.43 35700	5.91 1.80	1.48 1.48
SCZ 30	24.02 610.0	13.39 340.0	0.433 11.0	8.88 188.00	60.68 90.30	30.31 148.00	40.92 2200	46.56 2503.2	273.88 37400	5.91 1.80	1.48 1.48

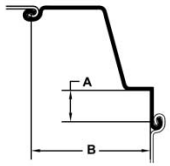
SKZ/SCZ

SKZ/SCZ Cold Formed Steel Sheet Piling

Corner Piles



B2 Corner Pile



B3 Corner Pile

SCZ 14 - SCZ 16
A = 5.0 inches (127.0 mm)
B = 23.5 inches (596.9 mm)

SKZ 20 - SKZ 25
A = 5.0 inches (127.0 mm)
B = 23.5 inches (596.9 mm)

SCZ 17 - SCZ 21
A = 5.0 inches (127.0 mm)
B = 24.95 inches (633.7 mm)

SCZ 22 - SCZ 30
A = 5.0 inches (127.0 mm)
B = 19.0 inches (482.6 mm)

Delivery Conditions & Tolerances

	ASTM	
Mass	± 2.5%	
Length	+ 5 inches	– 0 inches
Interlock Opening	± 0.08 inches	
Straightness	0.2% of the length	
Twisting	0.4% of the width	

Maximum Rolled Lengths*

SKZ, SCZ	70 feet	(21.3 m)

* Longer lengths may be possible upon request.

Optional Accessories

Sheet Pile Protector

Waler

Cap

Sheet Pile Protector

AZ Sections (Skyline)

AZ

AZ Hot Rolled Steel Sheet Piling

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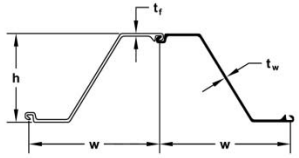


SECTION	Width (w) in (mm)	Height (h) in (mm)	THICKNESS Flange (t_f) in (mm)	THICKNESS Web (t_w) in (mm)	Cross Sectional Area in²/ft (cm²/m)	WEIGHT Pile lb/ft (kg/m)	WEIGHT Wall lb/ft² (kg/m²)	SECTION MODULUS Elastic in³/ft (cm³/m)	SECTION MODULUS Plastic in³/ft (cm³/m)	Moment of Inertia in⁴/ft (cm⁴/m)	COATING AREA Both Sides ft²/ft of single (m²/m)	COATING AREA Wall Surface ft²/ft² (m²/m²)
AZ 12	26.38 670	11.89 302.0	0.335 8.50	0.335 8.50	5.94 125.7	44.42 66.10	20.22 98.70	22.3 1200	26.2 1409	132.8 18140	5.45 1.66	1.23 1.23
AZ 13	26.38 670	11.93 303.0	0.375 9.50	0.375 9.50	6.47 136.9	48.38 72.00	22.02 107.50	24.2 1300	28.4 1528	144.3 19700	5.45 1.66	1.23 1.23
AZ 14	26.38 670	11.97 304.0	0.413 10.50	0.413 10.50	7.03 148.9	52.62 78.30	23.94 116.90	26.0 1400	30.7 1651	156.0 21300	5.45 1.66	1.23 1.23
AZ 12-770	30.31 770	13.52 343.5	0.335 8.50	0.335 8.50	5.67 120.1	48.78 72.60	19.31 94.30	23.2 1245	27.5 1480	156.9 21430	6.10 1.86	1.20 1.20
AZ 13-770	30.31 770	13.54 344.0	0.354 9.00	0.354 9.00	5.94 125.8	51.14 76.10	20.24 98.80	24.2 1300	28.8 1546	163.7 22360	6.10 1.86	1.20 1.20
AZ 14-770	30.31 770	13.56 344.5	0.375 9.50	0.375 9.50	6.21 131.5	53.42 79.50	21.14 103.20	25.2 1355	30.0 1611	170.6 23300	6.10 1.86	1.20 1.20
AZ 17	24.80 630	14.92 379.0	0.335 8.50	0.335 8.50	6.53 138.3	45.96 68.40	22.24 108.60	31.0 1665	36.2 1944	231.3 31580	5.64 1.72	1.35 1.35
AZ 18	24.80 630	14.96 380.0	0.375 9.50	0.375 9.50	7.11 150.4	49.99 74.40	24.19 118.10	33.5 1800	39.1 2108	250.4 34200	5.64 1.72	1.35 1.35
AZ 19	24.80 630	15.00 381.0	0.413 10.50	0.413 10.50	7.74 163.8	54.43 81.00	26.34 128.60	36.1 1940	42.3 2271	270.8 36980	5.64 1.72	1.35 1.35
AZ 17-700	27.56 700	16.52 419.5	0.335 8.50	0.335 8.50	6.28 133.0	49.12 73.10	21.38 104.40	32.2 1730	37.7 2027	265.3 36230	6.10 1.86	1.33 1.33
AZ 18-700	27.56 700	16.54 420.0	0.354 9.00	0.354 9.00	6.58 139.2	51.41 76.50	22.39 109.30	33.5 1800	39.4 2116	276.8 37800	6.10 1.86	1.33 1.33
AZ 19-700	27.56 700	16.56 420.5	0.375 9.50	0.375 9.50	6.88 145.6	53.76 80.00	23.41 114.30	34.8 1870	41.0 2206	288.4 39380	6.10 1.86	1.33 1.33
AZ 25	24.80 630	16.77 426.0	0.472 12.00	0.441 11.20	8.74 185.0	61.49 91.50	29.74 145.20	45.7 2455	53.4 2873	382.6 52250	5.91 1.80	1.41 1.41
AZ 26	24.80 630	16.81 427.0	0.512 13.00	0.480 12.20	9.35 198.0	65.72 97.80	31.79 155.20	48.4 2600	56.9 3059	406.5 55510	5.91 1.80	1.41 1.41
AZ 28	24.80 630	16.85 428.0	0.551 14.00	0.520 13.20	9.97 211.1	70.15 104.40	33.94 165.70	51.2 2755	60.5 3252	431.6 58940	5.91 1.80	1.41 1.41
AZ 24-700	27.56 700	18.07 459.0	0.441 11.20	0.441 11.20	8.23 174.1	64.30 95.70	28.00 136.70	45.2 2430	53.5 2867	408.8 55820	6.33 1.93	1.38 1.38
AZ 26-700	27.56 700	18.11 460.0	0.480 12.20	0.480 12.20	8.84 187.2	69.12 102.90	30.10 146.90	48.4 2600	57.1 3070	437.3 59720	6.33 1.93	1.38 1.38
AZ 28-700	27.56 700	18.15 461.0	0.520 13.20	0.520 13.20	9.46 200.2	73.93 110.00	32.19 157.20	51.3 2760	60.9 3273	465.9 63620	6.33 1.93	1.38 1.38
AZ 37-700	27.56 700	19.65 499.0	0.669 17.00	0.480 12.20	10.68 226.0	83.46 124.20	36.33 177.40	68.9 3705	79.2 4260	676.6 92400	6.76 2.06	1.46 1.46
AZ 39-700	27.56 700	19.69 500.0	0.709 18.00	0.520 13.20	11.34 240.0	88.63 131.90	38.59 188.40	72.5 3900	83.7 4500	714.0 97500	6.76 2.06	1.46 1.46
AZ 41-700	27.56 700	19.72 501.0	0.748 19.00	0.559 14.20	12.00 254.0	93.74 139.50	40.84 199.40	76.2 4095	88.3 4745	751.4 102610	6.76 2.06	1.46 1.46
AZ 46	22.83 580	18.94 481.0	0.709 18.00	0.551 14.00	13.76 291.2	89.10 132.60	46.82 228.60	85.5 4595	98.5 5295	808.8 110450	6.23 1.90	1.63 1.63
AZ 48	22.83 580	18.98 482.0	0.748 19.00	0.591 15.00	14.48 306.5	93.81 139.60	49.28 240.60	89.3 4800	103.3 5553	847.1 115670	6.23 1.90	1.63 1.63
AZ 50	22.83 580	19.02 483.0	0.787 20.00	0.630 16.00	15.22 322.2	98.58 146.70	51.80 252.9	93.3 5015	108.2 5816	886.5 121060	6.23 1.90	1.63 1.63

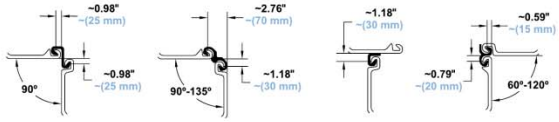
AZ

AZ Hot Rolled Steel Sheet Piling

Available Steel Grades								
AMERICAN			CANADIAN			EUROPEAN		
ASTM	YIELD STRENGTH (ksi)	YIELD STRENGTH (MPa)	CSA G40.21	YIELD STRENGTH (ksi)	YIELD STRENGTH (MPa)	EN 10248	YIELD STRENGTH (ksi)	YIELD STRENGTH (MPa)
A 328	39	270	Grade 260 W	38	260	S 240 GP	35	240
A 572 Grade 42	42	290	Grade 300 W	43	297	S 270 GP	39	270
A 572 Grade 50	50	345	Grade 350 W	51	355	S 320 GP	46	315
A 572 Grade 55	55	380	Grade 400 W	58	400	S 355 GP	51	355
A 572 Grade 60	60	415				S 390 GP	57	390
A 572 Grade 65	65	450				S 430 GP	62	430
A 690	50	345				S 460 AP	67	460
A 690*	57	390						

*Not available for AZ 37-700 and larger.

Corner Piles



C 14 Weight: 9.68 lbs/ft (14.4 kg/m)

Omega 18 Weight: 12.10 lbs/ft (18.0 kg/m)

C 9 Weight: 6.25 lbs/ft (9.3 kg/m)

Delta 13 Weight: 8.73 lbs/ft (13.0 kg/m)

Delivery Conditions & Tolerances

	ASTM A 6		EN 10248	
Mass	± 2.5%		± 5%	
Length	+ 5 inches	– 0 inches	± 200 mm	
Height			± 7 mm	
Thickness			≤ 8.5 mm	± 0.5 mm
			> 8.5 mm	± 6%
Width			± 2%	
Double Pile Width			± 3%	
Straightness			0.2% of the length	
Ends out of Square			2% of the width	

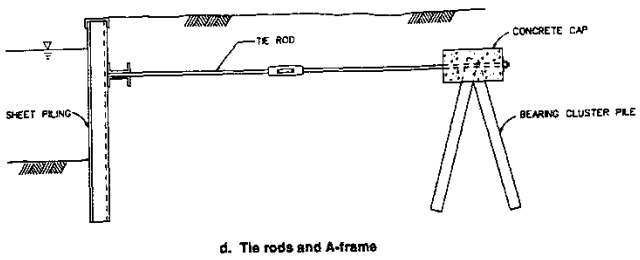
Maximum Rolled Lengths*

AZ	101.7 feet	(31.0 m)
C 9	59.1 feet	(18.0 m)
C 14	59.1 feet	(18.0 m)
Delta 13	59.1 feet	(18.0 m)
Omega 18	52.0 feet	(16.0 m)

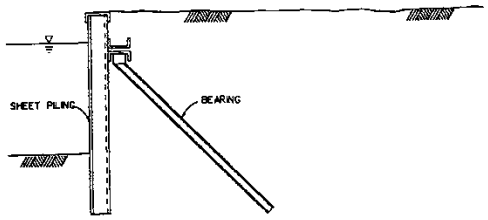
* Longer lengths may be possible upon request.

Cantilever and Anchored Walls

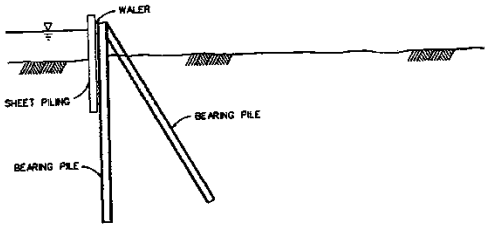
- Anchored Walls
  - Walls which have additional supports buried in the soil (tiebacks)



d. Tie rods and A-frame



e. Steel H-pile tension anchors

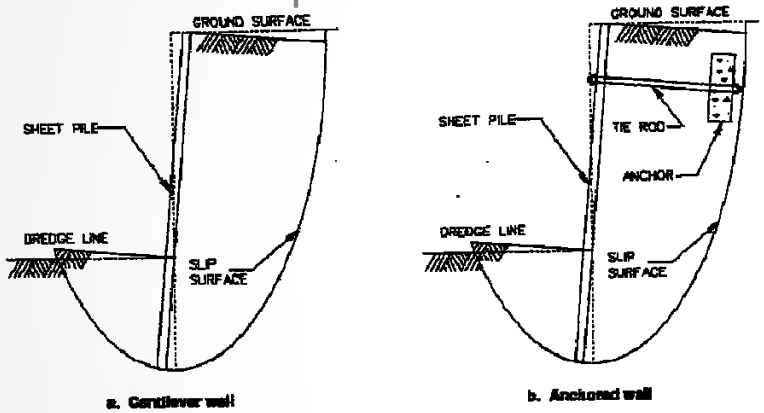


f. Steel H-pile anchors

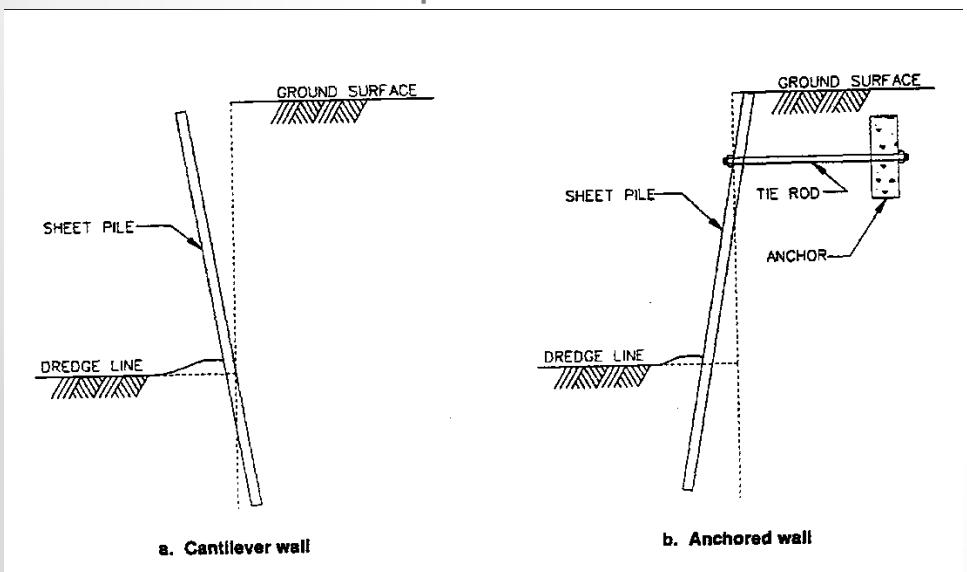
- Cantilever Walls
  - Walls which have no additional supports, and which rely on the lateral earth pressures in the lower portion of the wall to support the earth in the upper portion
  - Limited in height and soil type
  - Almost exclusively done with steel piling
  - Generally restricted to temporary structures

Failure of Sheet Pile Walls

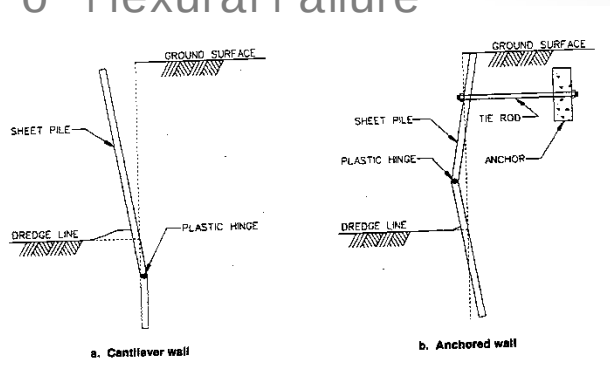
- Geotechnical Failure
  - Deep Seated Failure



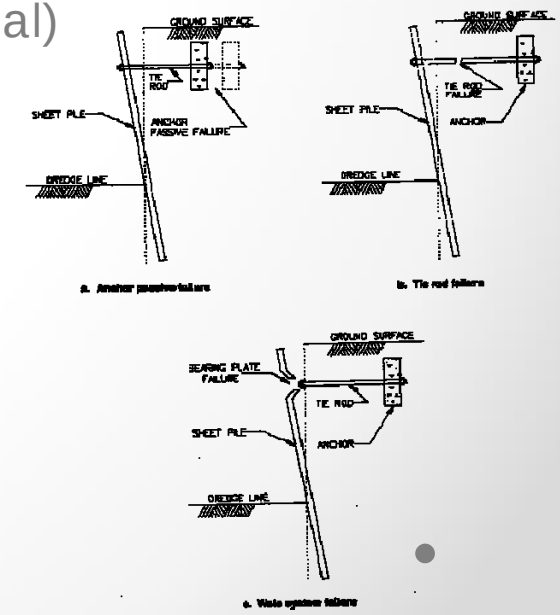
  - Inadequate Penetration



- Structural Failure
  - Flexural Failure



  - Anchorage Failure (can be geotechnical)

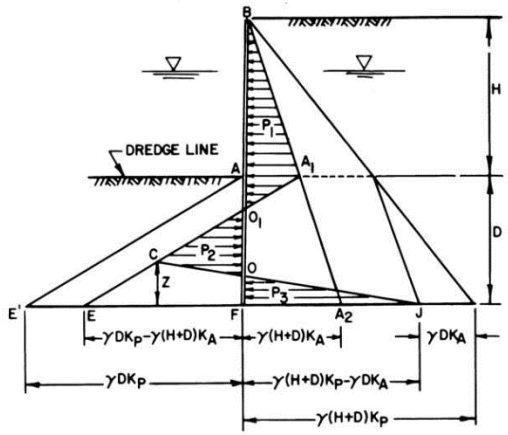


Methods of Solution for Cantilever Walls

- Conventional Method
  - Involves analysing active and passive pressures on sheet pile wall per layer
  - Traditionally the most common method used
  - Versatile but requires some experience for proficiency
  - Complex soil profiles can be difficult
- Simplified Method
  - Variation of conventional method
  - Eliminates problems at wall toe
  - Still requires some proficiency
- Chart Method
  - Very straightforward to use
  - Only applicable to simplest cases
  - Good check on other methods
- Closed Form Solution
  - Math complex but more straightforward
  - Limited number of cases
- Computer Software
  - For complex soil profiles, only practical solution

Design of Cantilever Walls: Conventional Method

NOTE: WATER LEVELS CAN BE DIFFERENT ON OPPOSITE SIDES DUE TO PUMPING, TIDAL FLUCTUATIONS AND OTHER REASONS.



1. Assume a trial depth of penetration, D. This may be estimated from the following approximate correlation.

Standard Penetration Resistance, N Blows/foot	Depth of Penetration*
0 - 4	2.0H
5 - 10	1.5H
11 - 30	1.25H
31 - 50	1.0H
+50	0.75H

* H = height of piling above dredge line

2. Determine the active and passive lateral pressure using appropriate coefficients of lateral earth pressure. If the Coulomb method is used, it should be used conservatively for the passive pressure.

3. Satisfy the requirements of static equilibrium: the sum of the forces in the horizontal direction must be zero and the sum of the moments about any point must be zero. The sum of the horizontal forces may be written in terms of pressure areas:

$$\Delta(\overrightarrow{EA_1A_2}) - \Delta(\overleftarrow{FBA_2}) - \Delta(\overleftarrow{ECJ}) = 0$$

Solve the above equation for the distance, Z. For a uniform granular soil,

$$Z = \frac{K_P D^2 - K_A (H+D)^2}{(K_P - K_A)(H+2D)}$$

FIGURE 23
Analysis for Cantilever Wall

4. Take moments about point F. If sum of moments is other than zero, readjust D and repeat calculations until sum of moments around F is zero.

5. Compute maximum moment at point of zero shear.

6. Increase D by 20% - 40% to result in approximate factor of safety of 1.5 to 2.

Notes:

A) For cantilever or anchored sheet pile walls, you may use either Rankine earth pressure coefficients for both Ka and Kp or the AASHTO scheme (Coulomb Ka/ log-spiral Kp).

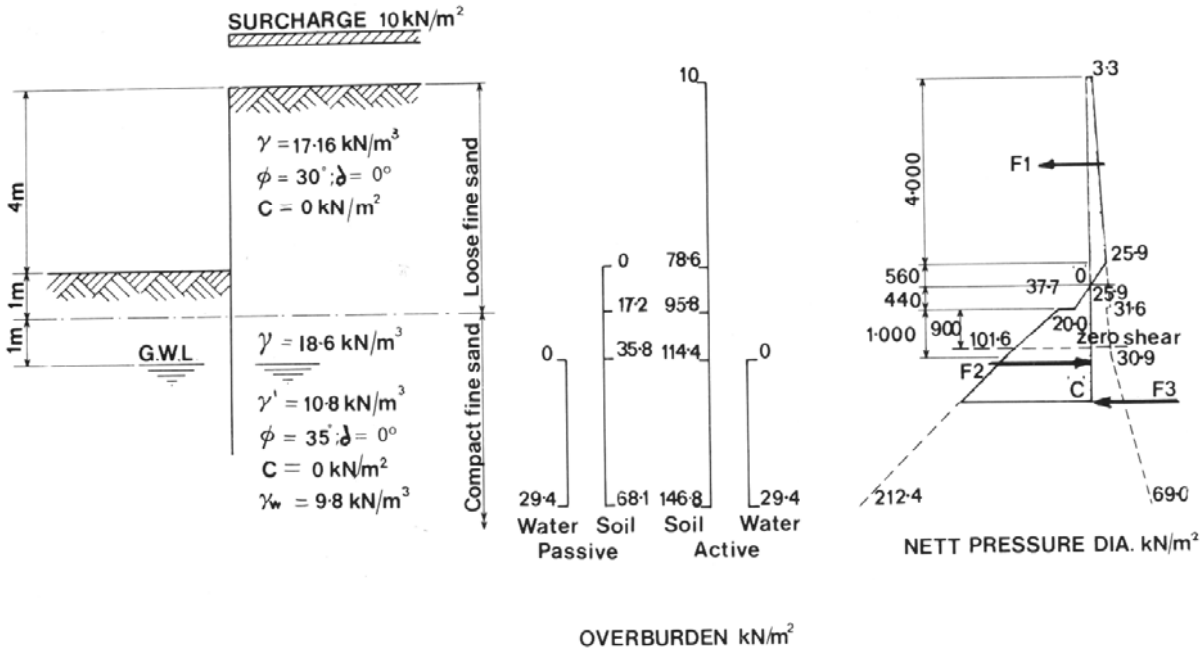
B) Re item 6, a better of way of including the factor of safety is to divide the Kp by 1.5-2. Once this is done, no further consideration of factor of safety is necessary. Murthy suggests this for anchored walls but this is also acceptable for cantilever walls as well, and is better practice in both cases.

C) Do not confuse the method in 6 with the D increase in the "simplified" method discussed in Murthy. They are two entirely different factors. The D increase for the simplified method is a result of the method, not a factor of safety.

Cantilever Sheet Pile Example

(Cohesionless Soils)

Cantilever Wall — Example



Active Pressure $p_a = \gamma.h\ K_a - 2c\sqrt{K_a} + p_w$

Passive Pressure $p_p = \gamma.h\ K_p + 2c\sqrt{K_p} + p_w$

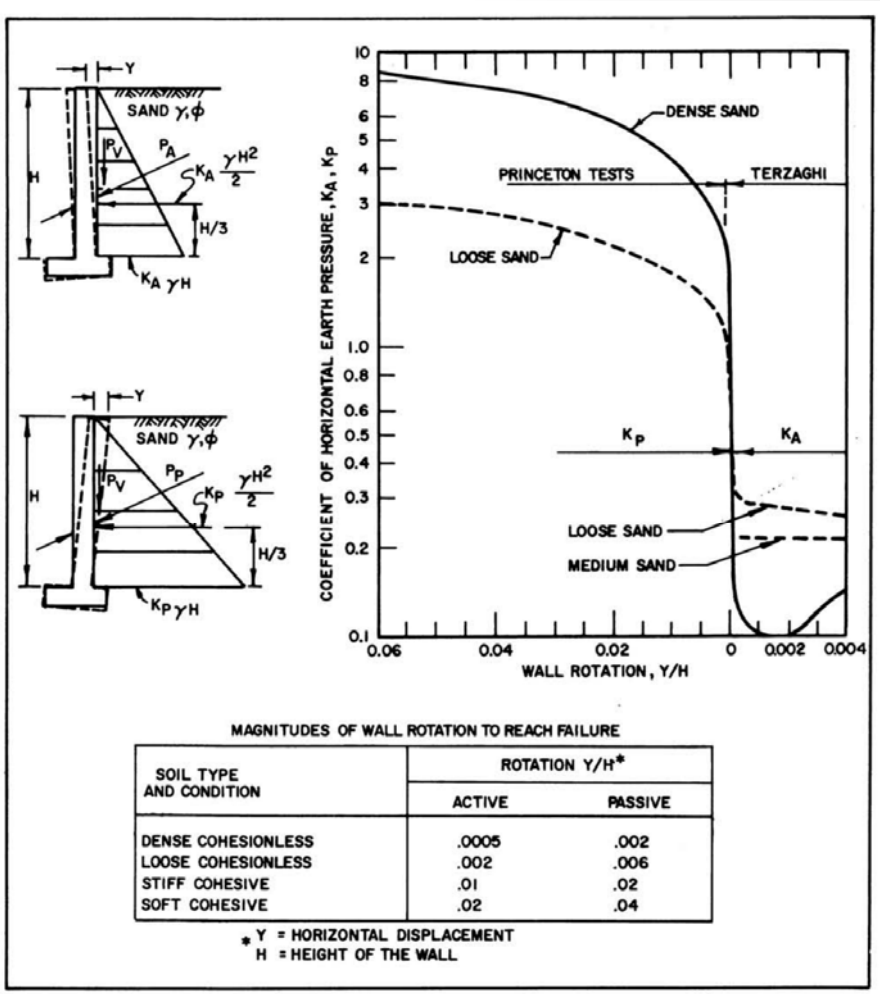
The coefficients of earth pressures are obtained from the tables in the section on earth and water pressures.

Loose fine sand	$K_a = 0{\cdot}33$	$K_p = 3{\cdot}0$
Compact fine sand	$K_a = 0{\cdot}27$	$K_p = 3{\cdot}7$

Note: Wall friction has been ignored in this example, however its beneficial effect can be included at the discretion of the engineer.

SPW 2006

- Simple software to use, does not require installation
- Input according to instructions
- For active-passive stroke, use chart at right
  - Complete stroke Y/H should be sum of active and passive rotation values, depending upon the soil
  - Y/H sum is then multiplied by height H (as shown) to determine stroke



MAGNITUDES OF WALL ROTATION TO REACH FAILURE

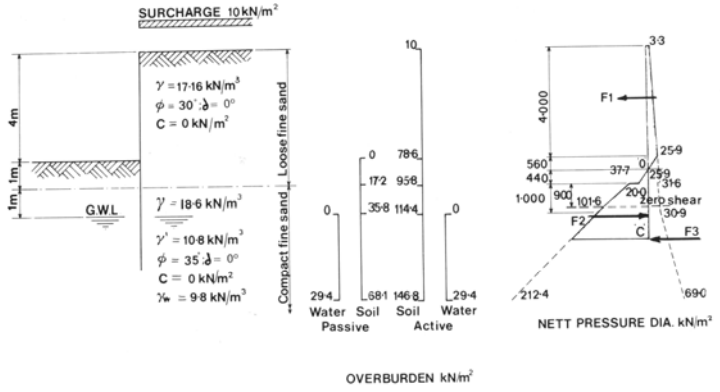
SOIL TYPE AND CONDITION	ROTATION Y/H*	
	ACTIVE	PASSIVE
DENSE COHESIONLESS	.0005	.002
LOOSE COHESIONLESS	.002	.006
STIFF COHESIVE	.01	.02
SOFT COHESIVE	.02	.04

* Y = HORIZONTAL DISPLACEMENT
H = HEIGHT OF THE WALL

FIGURE 1
Effect of Wall Movement on Wall Pressures

Cantilever Sheet Pile Example (Cohesionless Soils)

Cantilever Wall — Example



Active Pressure $p_a = \gamma.h\ K_a - 2c\sqrt{K_a} + p_w$

Passive Pressure $p_p = \gamma.h\ K_p + 2c\sqrt{K_p} + p_w$

The coefficients of earth pressures are obtained from the tables in the section on earth and water pressures.

Loose fine sand $K_a = 0{\cdot}33$ $K_p = 3{\cdot}0$
Compact fine sand $K_a = 0{\cdot}27$ $K_p = 3{\cdot}7$

Note: Wall friction has been ignored in this example, however its beneficial effect can be included at the discretion of the engineer.

p_a at ground level = 10 x 0·33 = 3·3 kN/m²
p_a at 4 m below ground level in loose sand = 78·6 x 0·33 = 25·9 kN/m²
p_a at 5 m below ground level in loose sand = 95·8 x 0·33 = 31·6 kN/m²
p_a at 5 m below ground level in compact sand = 95·8 x 0·27 = 25·9 kN/m²
p_a at 6 m below ground level in compact sand = 114·4 x 0·27 = 30·9 kN/m²
p_a at 9 m below ground level in compact sand = 146·8 x 0·27 + 29·4 = 69·0 kN/m²

p_p at 4 m below ground level in loose sand = 0 kN/m²
p_p at 5 m below ground level in loose sand = 17·2 x 3·0 = 51·6 kN/m²
p_p at 5 m below ground level in compact sand = 17·2 x 3·7 = 63·6 kN/m²
p_p at 6 m below ground level in compact sand = 35·8 x 3·7 = 132·5 kN/m²
p_p at 9 m below ground level in compact sand = 68·1 x 3·7 + 29·4 = 281·4 kN/m²

Nett p_p at 5 m below ground level in loose sand = 51·6 — 31·6 = 20·0 kN/m²
Nett p_p at 5 m below ground level in compact sand = 63·6 — 25·9 = 37·7 kN/m²
Nett p_p at 6 m below ground level in compact sand = 132·5 — 30·9 = 101·6 kN/m²
Nett p_p at 9 m below ground level in compact sand = 281·4 — 69·0 = 212·4 kN/m²

As the Pressure Diagram below 'O' is not uniform the depth O.C. is most easily derived by trial and error.

Try O.C. = 3·0 m

Moments about 'C'

3·3 x 4·000 x 5·560	= 73·4
22·6 x 4·000 x 0·5 x 4·893	= 221·2
25·9 x 0·560 x 0·5 x 3·373	= 24·5
— 20·0 x 0·440 x 0·5 x 2·707	= — 11·9
— 37·7 x 1·000 x 2·060	= — 77·7
— 63·9 x 1·000 x 0·5 x 1·893	= — 60·5
—101·6 x 1·560 x 0·780	= —123·6
— 57·6 x 1·560 x 0·5 x 0·520	= — 23·4
	22·0 kN/m

Hence the correct value of O.C. is slightly more than 3·0 m. However it is sufficiently accurate to take O.C. = 3·0.

Depth of cut-off required = 0·560 + 1·2 x 3·0 ≈ 4·2 m

Total Active Pressure

14·6 x 4	= 58·40
25·9 x 0·560 x 0·5	= 7·25
	65·65 kN

Zero Shear (Max. Bending Moment) occurs 5·9 m below ground level.

Moments about and above point of zero shear.

3·3 x 4·000 x 3·900	= 51·5
22·6 x 4·000 x 0·5 x 3·233	= 146·1
25·9 x 0·560 x 0·5 x 1·713	= 12·4
—20·0 x 0·440 x 0·5 x 1·047	= — 4·6
—37·7 x 0·900 x 0·450	= —15·2
—57·5 x 0·900 x 0·5 x 0·300	= — 7·8
	182·4 kN/m

Bending Moment on Piles = 182·4 kN/m

Z required = $\frac{182{\cdot}4 \times 1000 \times 100}{125 \times 100}$ = 1459 cm³/m

Z of Larssen 3/20 = 1665 cm³/m
Z of Frodingham 3N = 1688 cm³/m

Use either Frodingham 3N or Larssen 3/20 Piles x 8·2 m. long in Grade 43A steel

Input to SPW 2006

Loading Step : 1 | Right Side

No.	Soil Name	H	Wd	Ws	Zw	Cap	q	c	Ka	Kp	Kn	Dw
		m	kN/m³	kN/m³	m	m	kN/m²	kN/m²	--	--	--	m
1	Loose Fine Sanc	4.000	17.160	17.160	6.000	0.000	10.000	0.000	0.333	2.000	1.000	0.032
2	Loose Fine Sanc	1.000	17.160	17.160	6.000	0.000	10.000	0.000	0.333	2.000	0.500	0.032
3	Dense Fine San	1.000	18.600	18.600	6.000	0.000	10.000	0.000	0.270	2.470	0.426	0.010
4	ense Fine Sand	4.000	18.600	18.600	6.000	0.000	10.000	0.000	0.270	2.470	0.426	0.010

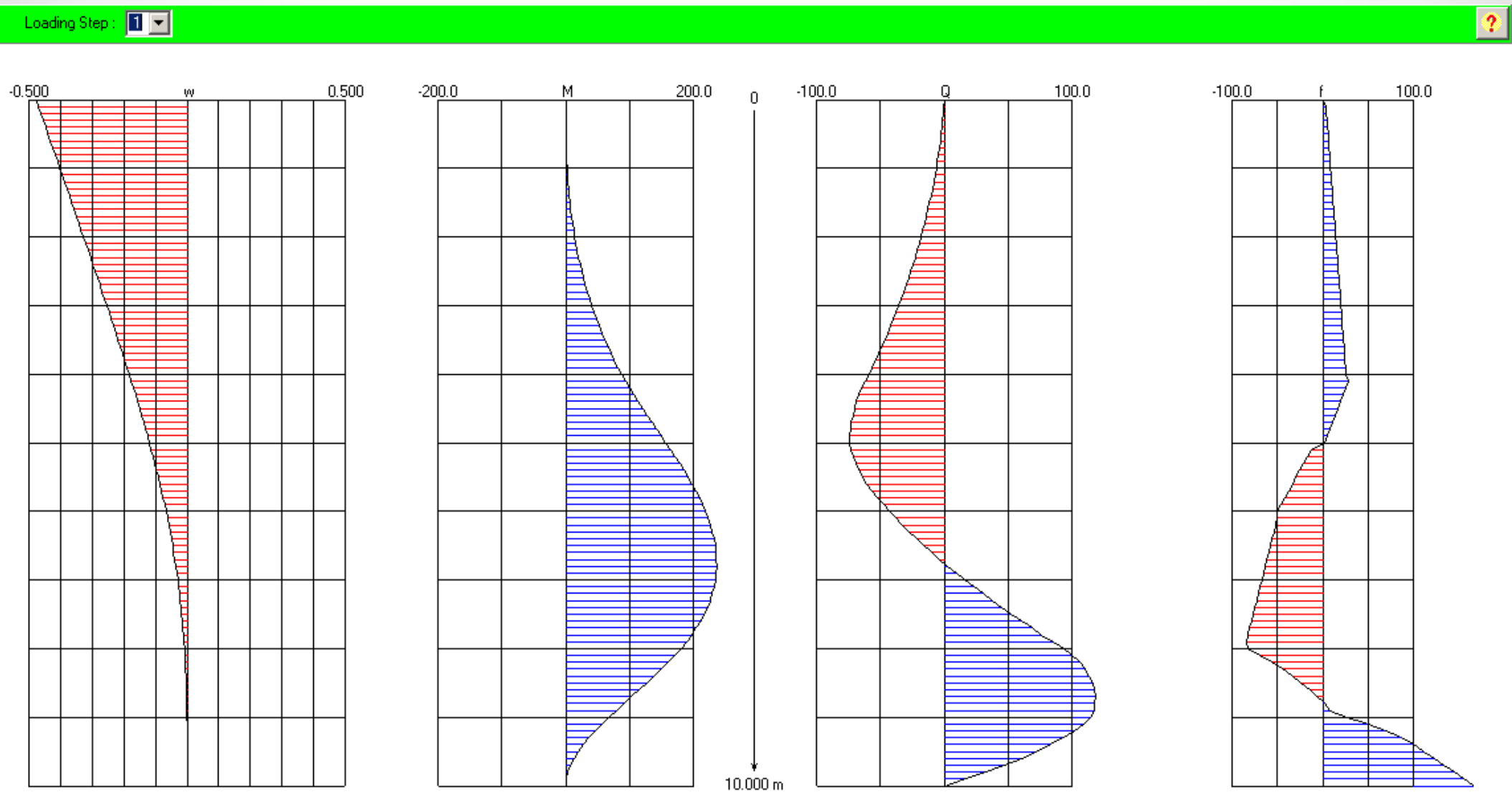
Loading Step : 1 | Left Side

No.	Soil Name	H	Wd	Ws	Zw	Cap	q	c	Ka	Kp	Kn	Dw
		m	kN/m³	kN/m³	m	m	kN/m²	kN/m²	--	--	--	m
1	Loose Fine Sanc	4.000	0.000	10.000	6.000	0.000	0.000	0.000	1.000	1.000	1.000	1.000
2	Loose Fine Sanc	1.000	17.160	17.160	6.000	0.000	0.000	0.000	0.333	2.000	0.500	0.032
3	Dense Fine San	1.000	18.600	18.600	6.000	0.000	0.000	0.000	0.270	2.470	0.426	0.010
4	ense Fine Sand	4.000	18.600	18.600	6.000	0.000	0.000	0.000	0.270	2.470	0.426	0.010

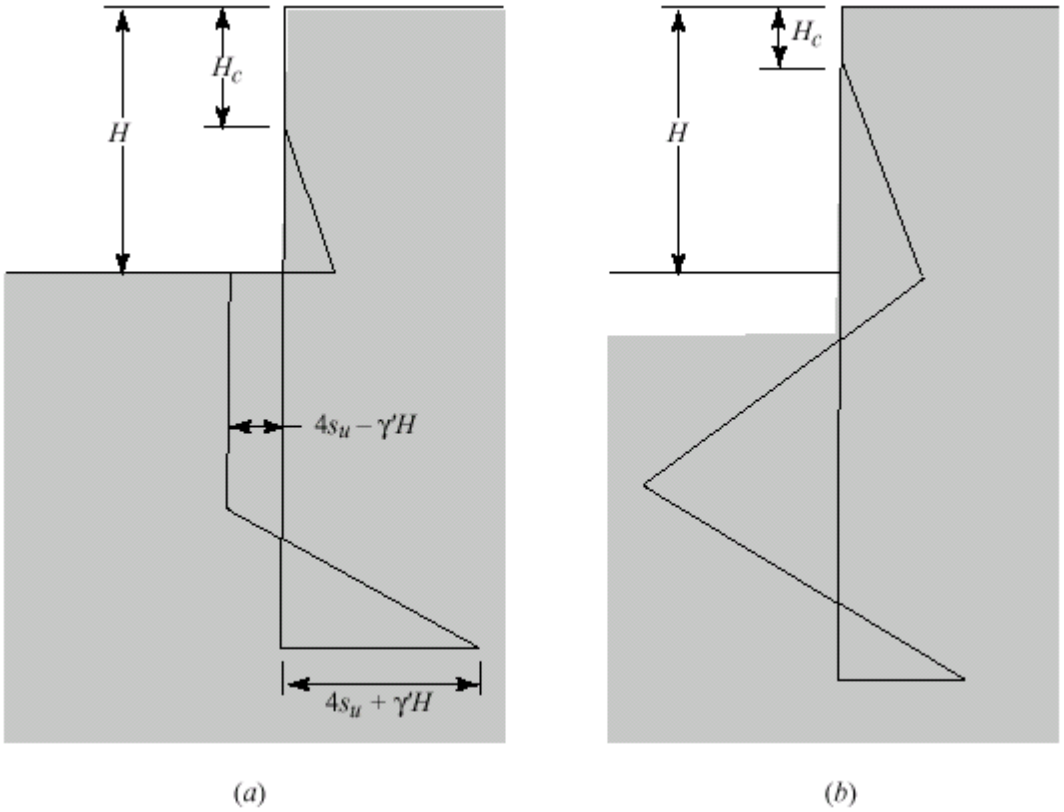
Loading Step : 1

No.	Depth	Fx	Fa	Dw
	m	kN/m	kN/m	m
0	0.000	0.000	0.000	1.000
1	4.000	0.000	0.000	1.000
2	5.000	0.000	0.000	1.000
3	6.000	0.000	0.000	1.000
4	10.000	0.000	0.000	1.000

Solution to Example from SPW 2006



Cantilever Piles in Clay



- Two step analysis
  - Short term, where $\varphi = 0$ and $c = s_u$ (analyse for cohesion only)
  - Long term, where $\varphi > 0$ and $c > 0$ (use strengths from S (C-D) tests)
  - Include critical height considerations

Questions