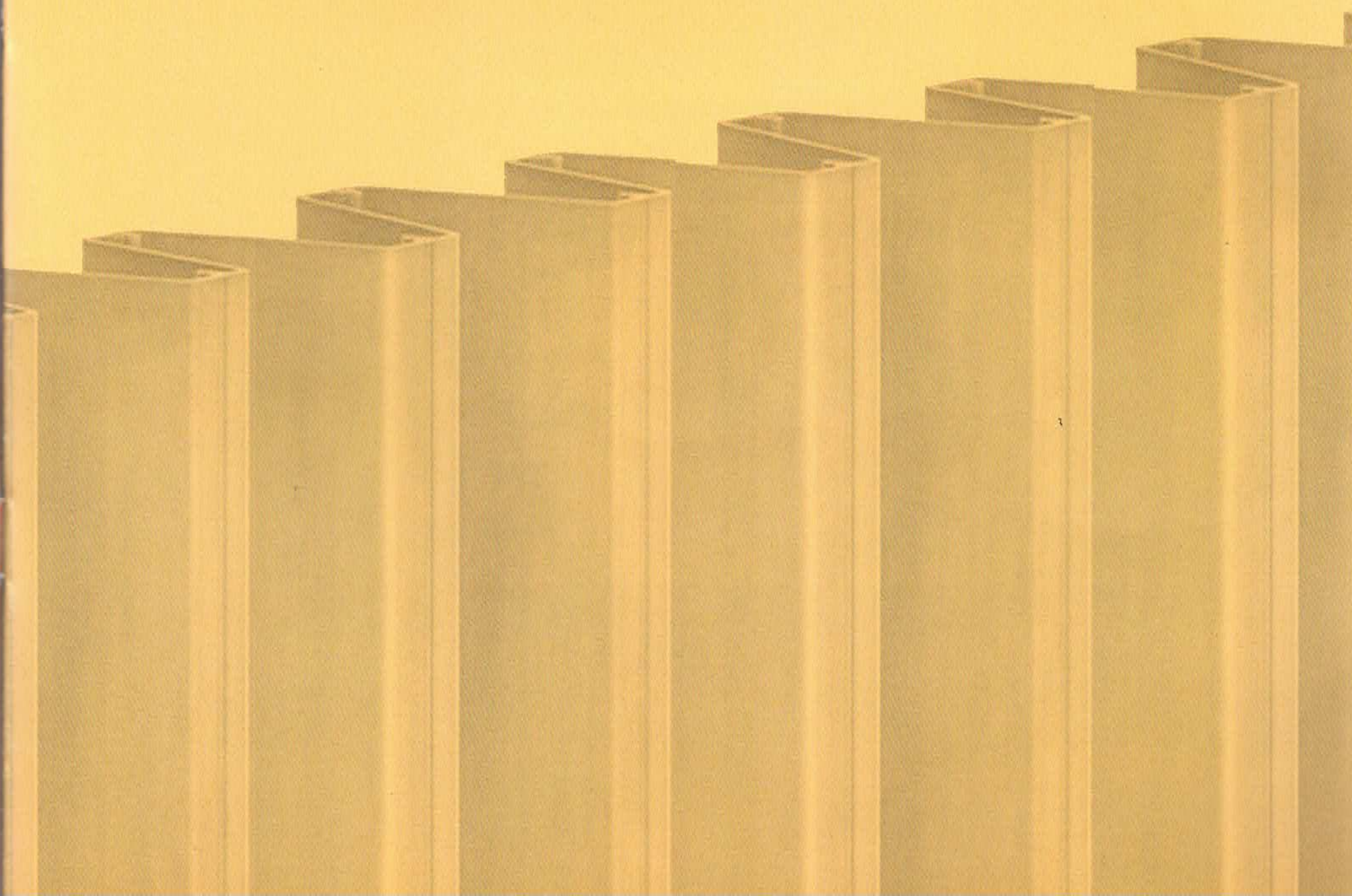
Sheet Piling Handbook

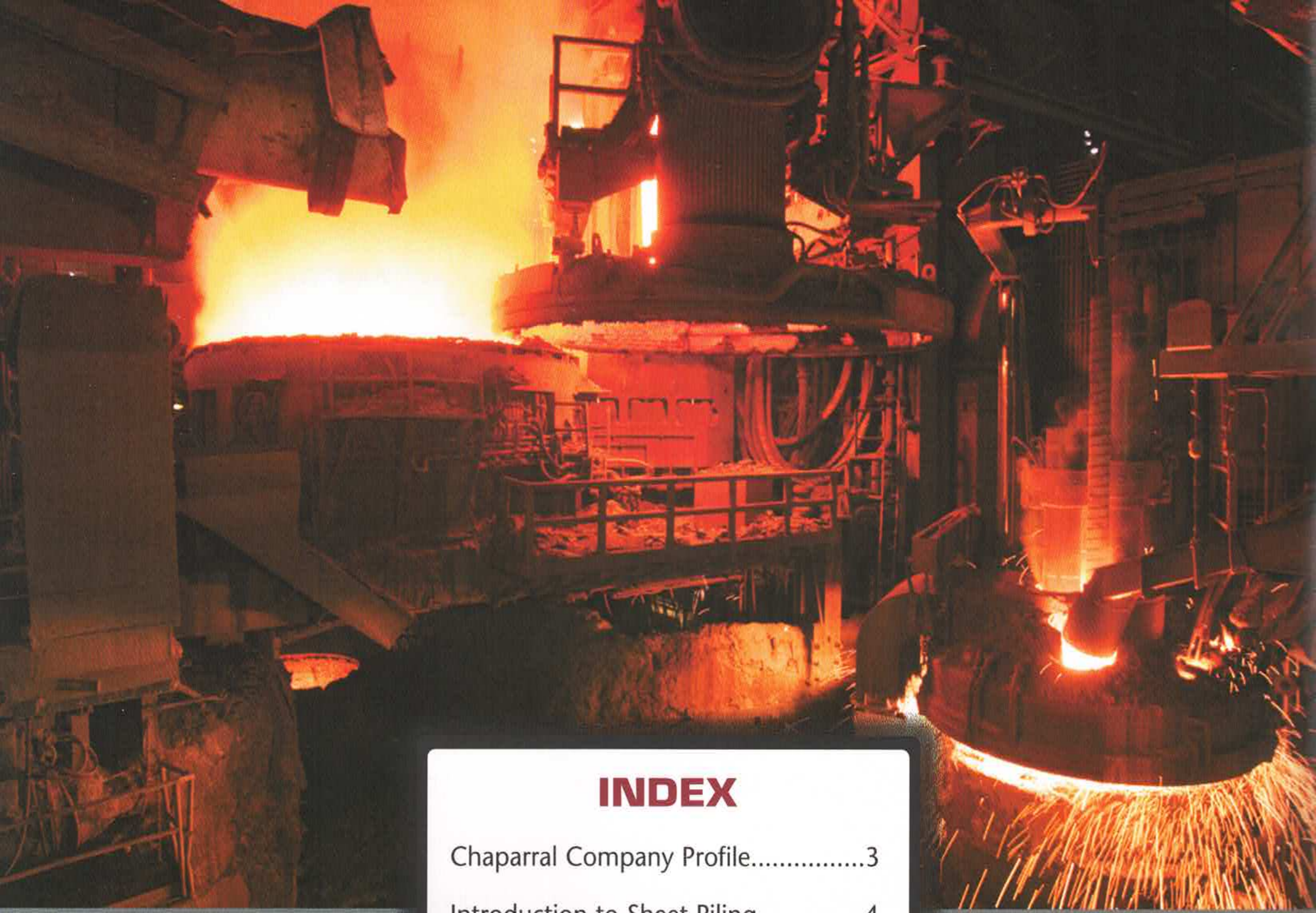
CHAPARRAL

CHAPARRAL IS A LEADING INNOVATOR AND MANUFACTURER OF STEEL SHEET PILING THAT CONCENTRATES ON DEVELOPING SAFE AND COST EFFICIENT SOLUTIONS FOR THE CONSTRUCTION INDUSTRY.

CHAPARRAL'S GOAL IS TO ACHIEVE GROWTH VIA NEW PRODUCT DEVELOPMENT AND BY EXCEEDING OUR CUSTOMERS' EXPECTATIONS.

CHAPARRAL
STEEL SHEET PILING
2006





INDEX

Cover sheet piling art, and additional photos and illustrations, courtesy of L.B. Foster Company

COMPANY PROFILE

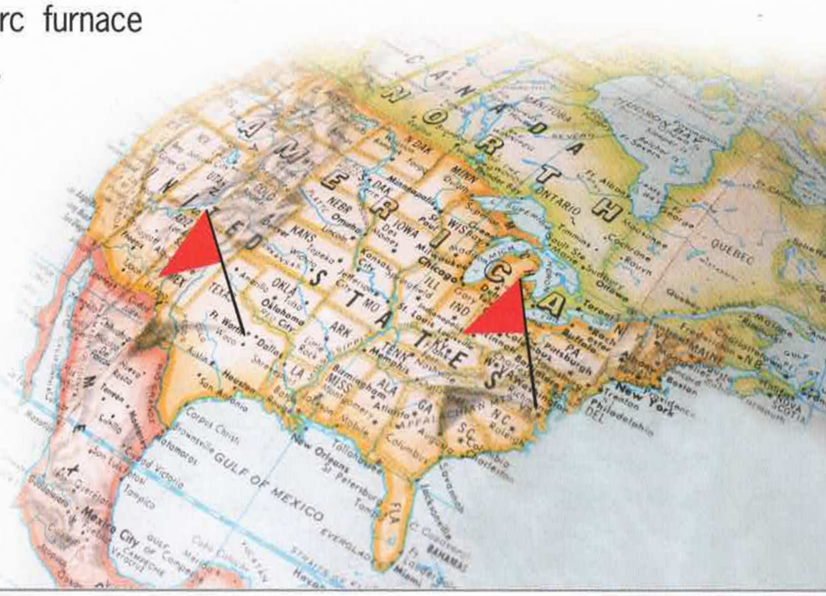
Chaparral began in 1973 with the construction of a steel plant in Midlothian, Texas, and has since added an additional plant in Petersburg, Virginia. Chaparral is the second largest producer of structural steel beams in North America and the largest producer of steel sheet piling in North America. Annual sales are in excess of $1 billion USD and the company is traded on the NASDAQ under the symbol of CHAP.

Texas Plant

The corporate office and steel plant are located 30 miles (48 kilometers) southwest of Dallas, Texas, in the city of Midlothian. The plant is comprised of an automobile shredder, metals separator, two electric arc furnaces for the melting operations, and three rolling mills. The three rolling mills include a bar mill which produces hot rolled round bars for specialty steel forging applications and also reinforcing bars for construction. The other two rolling mills produce hot rolled structural shapes including beams up to 24 inches (610 mm), channels up to 12 inches (305 mm), and PS (flat web) sheet piling. The combined capacity of the Texas operations is 1.8 million tons per year.

Virginia Plant

Chaparral built a state-of-the-art $500 million steel mill in Petersburg, Virginia, near the city of Richmond, in 1998. This mill produces hot rolled structural shapes including beams up to 36 inches (915 mm) and the full range of Z-profile sheet piling sections. The facility is the most modern sheet piling mill in the world with annual capacity just over 1.0 million tons with 450+ employees. The plant is comprised of an automobile shredder, electric arc furnace melting operation, and rolling mill.



Introduction to Sheet Piling

Steel sheet piling is a rolled structural steel section with interlocks on the flange tips which enables the joining of sections to form a continuous wall.

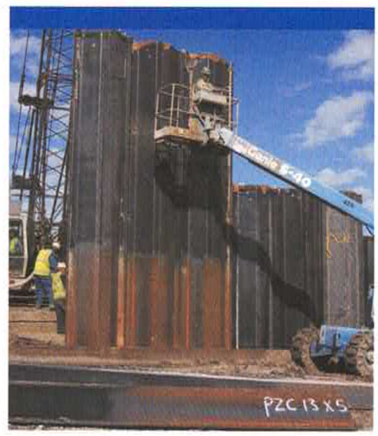
London Avenue Canal, New Orleans

Sheet Piling Applications

Permanent and temporary applications for steel sheet piling cover the entire construction industry:

- Marine
- Environmental
- Foundations
- Transportation

The interlocks permit the sheets to be set and driven as a continuous wall, which resists the movement of soil and water.



IHNC Levee Rebuilding, New Orleans

Sheet Piling Benefits and Advantages

- Readily available
- Reduced space requirements
- Reduced construction time
- Produced from recycled material
- Material longevity
- Typically lower overall construction costs

Chaparral Sheet Piling Sections may be divided into two types based on their end use:

1) Z-Profiles - sections used for beam strength in cantilevered and braced construction

- Retaining walls
- River cofferdams
- Braced excavations
- Tied bulkheads
- Bridge abutments
- Cut-off walls
- Foundations
- Levee construction

2) PS Profiles - sections used for interlock strength in cellular applications

- Bridge abutments
- Graving docks
- Bridge pier protection
- Deep draft bulkheads and docks
- Cofferdams to construct locks and dams
- Mooring dolphins
- Levee construction
- Erosion control

Z-Profiles (PZC and PZ)

Z-Profiles, with their optimum distribution of material, are the most efficient sheet piling sections available for bending strength. With the interlocks located on the outer fibers of the wall - rather than at the center line, as is the case with Arch or U-Profile sheet piling sections – the wall designer is assured of the published section modulus. The Z-Profile is the optimal section for both weight and strength.

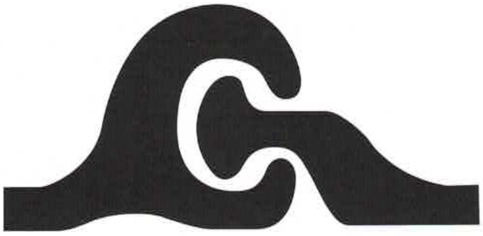
Interlock

The Ball-and-Socket Interlock was introduced in the United States in the late 1930's and continues to be the preferred interlock by piling contractors and engineers.

Chaparral produces Z-Profiles with the ball and socket interlock at our mill in Petersburg, Virginia.

The advantages of the ball and socket interlock over Larssen and other interlocks are:

- Most rugged, durable, and flexible interlock available.
- Ideal for reuse in multiple projects.
- Higher "buy back/resale" value.
- Easier setting, driving, and extraction.
- Highest interlock strength relative to other Z-Profiles.
- Flexibility when setting - allows adjustment to wall length by swinging (rotating) sheets.



Chaparral Z-Profile Additional Advantages:

Only Chaparral sections incorporate geometry based upon the testing and research findings of Dr. Richard Hartman regarding transverse bending stresses. Dr. Hartman, in the 1990s, demonstrated that both longitudinal stresses and transverse stresses act within sheet piling sections.

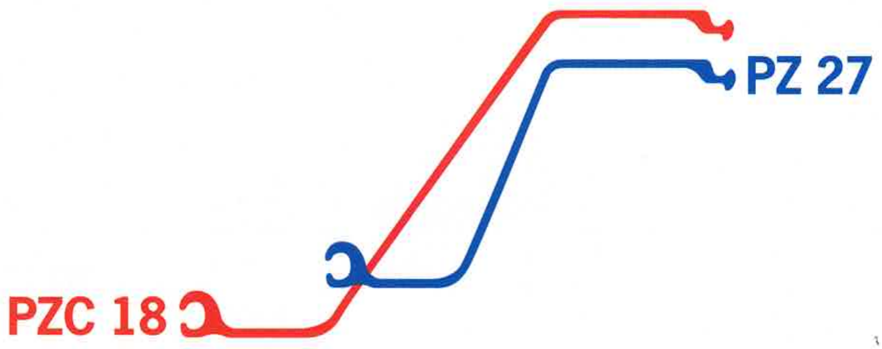
Longitudinal stresses are oriented in a vertical direction and are familiar to all engineers who design sheet piling structures. Accepted engineering practice is to design to 0.65 F_y in longitudinal bending. Transverse stresses are oriented in a horizontal direction and are dependent upon section geometry. In fact, transverse stresses can exceed longitudinal stresses in poorly proportioned sheet piling sections.

Chaparral sections are designed to minimize the effects of transverse stresses and maintain the structural integrity of the section.

More information on Dr. Hartman's research can be found at www.transversestress.com

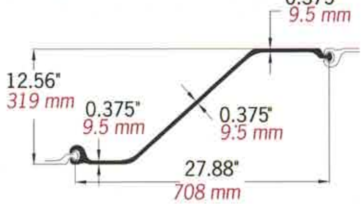
PZ and PZC Profiles and Properties

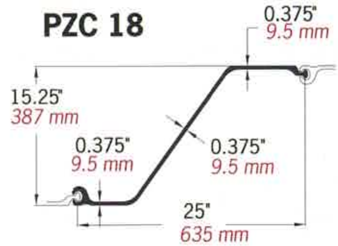
- **PZ** Traditional North American Sections with ball and socket interlocks.
- **PZC** Newest generation of wider, lighter and stronger sheet piling sections with ball and socket interlocks.



	PZC 18	PZ 27
Width	25.0 in.	18.0 in.
Weight	24.2 lbs/ft^2	27.7 lbs/ft^2
S.M.	33.5 in.^{3}/ft	31.0 in.^{3}/ft

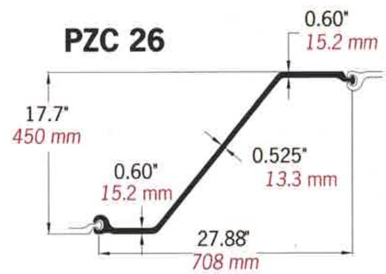
CHAPARRAL
PZC SHEET PILING PROPERTIES

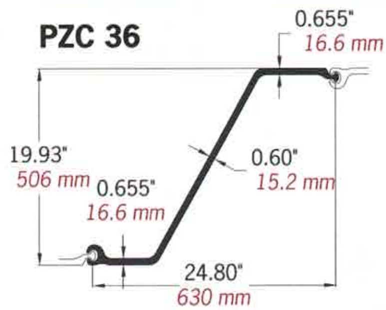




Section	Nominal Width in. (mm)	Wall Depth (Height) in. (mm)	Web Thickness in. (mm)	Flange Thickness in. (mm)	Per Single Section: Area in.² (cm²)	Per Single Section: Weight lbs/ft (kg/m)	Per Single Section: Moment of Inertia in.⁴ (cm⁴)	Per Single Section: Section Modulus in.³ (cm³)	Per Single Section: Total Surface Area ft²/ft (m²/m)	Per Single Section: Nominal Coating Area* ft²/ft (m²/m)	Per Unit of Wall: Area in.²/ft (cm²/m)	Per Unit of Wall: Weight lbs/ft² (kg/m²)	Per Unit of Wall: Moment of Inertia in.⁴/ft (cm⁴/m)	Per Unit of Wall: Section Modulus in.³/ft (cm³/m)
PZC 12	27.88	12.52	0.335	0.335	13.64	46.4	324.5	51.8	6.10	5.60	5.87	20.0	139.7	22.3
	708	318	8.5	8.5	88.0	69.1	13,510	850	1.86	1.71	124.3	97.6	19,080	1,200
PZC 13	27.88	12.56	0.375	0.375	14.82	50.4	353.0	56.2	6.10	5.60	6.38	21.7	152.0	24.2
	708	319	9.5	9.5	95.6	75.1	14,695	920	1.86	1.71	135.1	106.0	20,755	1,300
PZC 14	27.88	12.60	0.420	0.420	16.15	55.0	381.6	60.5	6.10	5.60	6.95	23.7	164.3	26.0
	708	320	10.7	10.7	104.2	81.8	15,890	990	1.86	1.71	147.2	115.5	22,445	1,400
PZC 17	25.00	15.21	0.335	0.335	13.64	46.4	491.8	64.6	6.10	5.60	6.55	22.3	236.1	31.0
	635	386	8.5	8.5	88.0	69.1	20,470	1,060	1.86	1.71	138.6	108.8	32,235	1,670
PZC 18	25.00	15.25	0.375	0.375	14.82	50.4	532.2	69.8	6.10	5.60	7.12	24.2	255.5	33.5
	635	387	9.5	9.5	95.6	75.1	22,155	1,145	1.86	1.71	150.6	118.2	34,890	1,800
PZC 19	25.00	15.30	0.420	0.420	16.16	55.0	576.3	75.3	6.10	5.60	7.75	26.4	276.6	36.1
	635	388	10.7	10.7	104.2	81.8	23,990	1,235	1.86	1.71	164.1	128.8	37,780	1,945
PZC 25	27.88	17.66	0.485	0.560	20.40	69.4	938.7	106.3	6.65	6.15	8.78	29.9	404.1	45.7
	708	449	12.3	14.2	131.6	103.3	39,075	1,740	2.03	1.87	185.9	145.9	55,190	2,455
PZC 26	27.88	17.70	0.525	0.600	21.72	73.9	994.3	112.4	6.65	6.15	9.35	31.8	428.1	48.4
	708	450	13.3	15.2	140.1	110.0	41,390	1,840	2.03	1.87	197.9	155.4	58,460	2,600
PZC 28	27.88	17.75	0.570	0.645	23.22	79.0	1,057.1	119.1	6.65	6.15	10.00	34.0	455.1	51.3
	708	451	14.5	16.4	149.8	117.6	44,000	1,950	2.03	1.87	211.6	166.1	62,145	2,755
PZC 34	24.80	19.89	0.563	0.618	22.79	77.5	1,311.9	131.9	6.65	6.15	11.03	37.5	634.8	63.8
	630	505	14.3	15.7	147.0	115.4	54,605	2,160	2.03	1.87	233.4	183.2	86,685	3,430
PZC 36	24.80	19.93	0.600	0.655	24.03	81.8	1,379.3	138.4	6.65	6.15	11.63	39.6	667.4	67.0
	630	506	15.2	16.6	155.0	121.7	57,410	2,270	2.03	1.87	246.1	193.2	91,140	3,600
PZC 38	24.80	19.97	0.642	0.697	25.51	86.8	1,459.6	146.1	6.65	6.15	12.34	42.0	706.3	70.7
	630	507	16.3	17.7	164.6	129.2	60,755	2,395	2.03	1.87	261.3	205.1	96,450	3,800

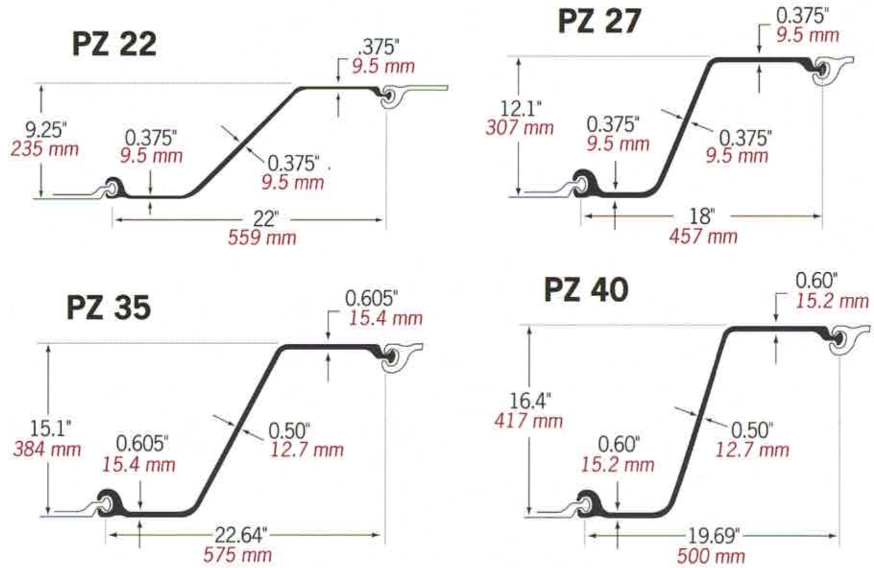
*Excludes socket interior and ball of interlock.





CHAPARRAL

PZ SHEET PILING PROPERTIES



Section	Nominal Width in. (mm)	Wall Depth (Height) in. (mm)	Web Thickness in. (mm)	Flange Thickness in. (mm)	Per Single Section: Area in.² (cm²)	Per Single Section: Weight lbs/ft (kg/m)	Per Single Section: Moment of Inertia in.⁴ (cm⁴)	Per Single Section: Section Modulus in.³ (cm³)	Per Single Section: Total Surface Area ft²/ft (m²/m)	Per Single Section: Nominal Coating Area* ft²/ft (m²/m)	Per Unit of Wall: Area in.²/ft (cm²/m)	Per Unit of Wall: Weight lbs/ft² (kg/m²)	Per Unit of Wall: Moment of Inertia in.⁴/ft (cm⁴/m)	Per Unit of Wall: Section Modulus in.³/ft (cm³/m)
PZ 22	22.00	9.25	0.375	0.375	12.20	41.5	156.0	33.7	4.96	4.46	6.65	22.6	85.1	18.4
	559	*235*	*9.5*	*9.5*	*78.7*	*61.8*	*6,495*	*555*	*1.51*	*1.36*	*140.9*	*110.6*	*11,620*	*990*
PZ 27	18.00	12.10	0.375	0.375	12.20	41.5	281.0	46.4	4.96	4.46	8.13	27.7	187.3	31.0
	457	*307*	*9.5*	*9.5*	*78.7*	*61.8*	*11,695*	*760*	*1.51*	*1.36*	*172.2*	*135.1*	*25,580*	*1,660*
PZ 35	22.64	15.10	0.500	0.605	19.40	66.0	697.1	92.3	5.83	5.33	10.28	35.0	369.5	48.9
	575	*384*	*12.7*	*15.4*	*125.2*	*98.2*	*29,015*	*1,515*	*1.78*	*1.62*	*217.7*	*170.8*	*50,455*	*2,635*
PZ 40	19.69	16.40	0.500	0.600	19.28	65.6	824.8	100.6	5.83	5.33	11.75	40.0	502.7	61.3
	500	*417*	*12.7*	*15.2*	*124.4*	*97.6*	*34,330*	*1,650*	*1.78*	*1.62*	*248.7*	*195.2*	*68,645*	*3,300*

*Excludes socket interior and ball of interlock.

PZ sheet piling is a traditional sheet piling profile produced in North America. These sections are named for weight. For example, PZ 35 weighs 35 pounds per square foot of wall.

PZC sections are the "latest generation" of sheet piling profiles and were developed to be lighter, wider, and stronger than the older traditional PZ sections. PZC profiles are named for their strength in metric designations. For example, PZC 18 has a Section Modulus of 1,800 cm³/meter. **PZC profiles should always be the designer's first choice in order to provide the end user the most efficient retention wall with the most efficient ratio of section modulus to weight. PZC profiles are listed on page 7.**

Connectors for Z-Profiles:

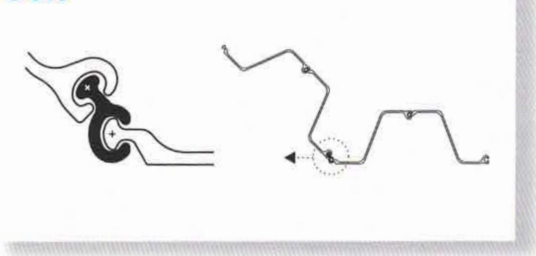
Extruded Connections

Extruded connections are suggested for Corners and Tees. Consistent quality control during extrusion combined with ease of use and efficiency of construction make these engineered products superior to traditional fabricated sections. These connectors are readily available directly from the mill with Z-Profile sheet piling.

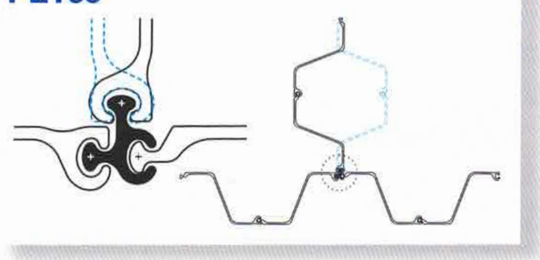
Advantages of extruded connectors are:

- Uniform, consistent quality product.
- Delivery made with sheet piling.
- Easily transported, handled, stored and installed.
- All possible configurations are stocked with sheet piling.

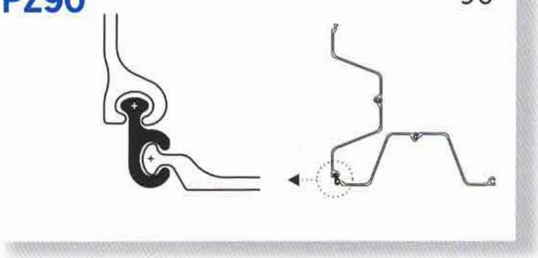
Colt 45°



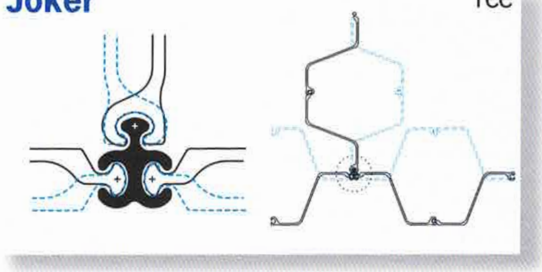
PZTee Tee



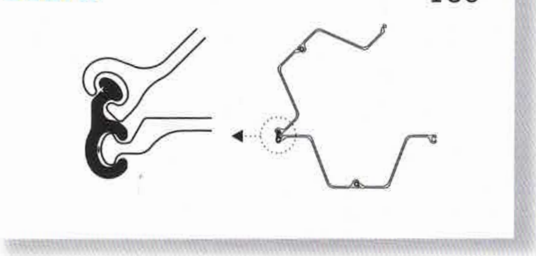
PZ90 90°



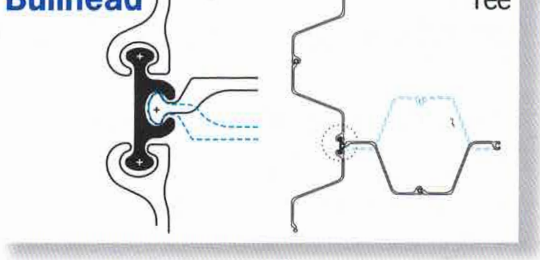
Joker Tee



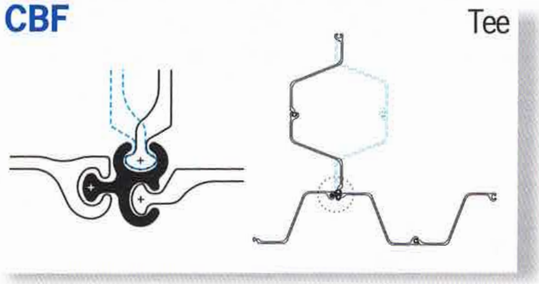
Cobra 135°



Bullhead Tee



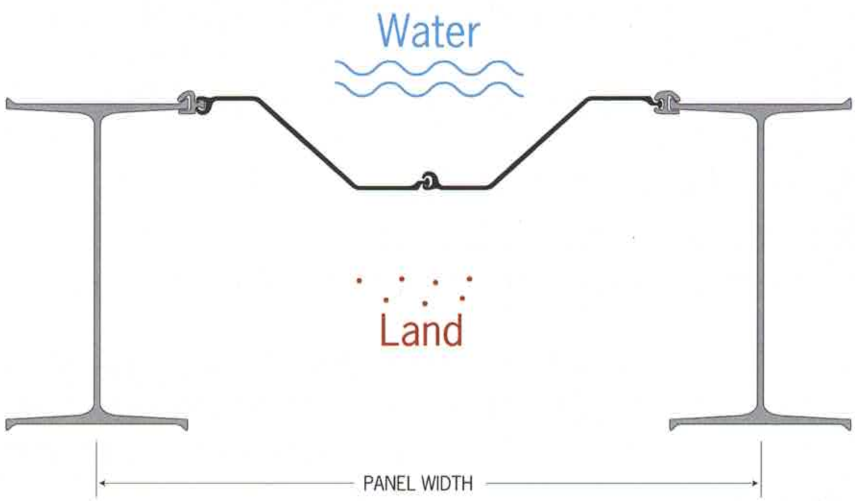
CBF Tee

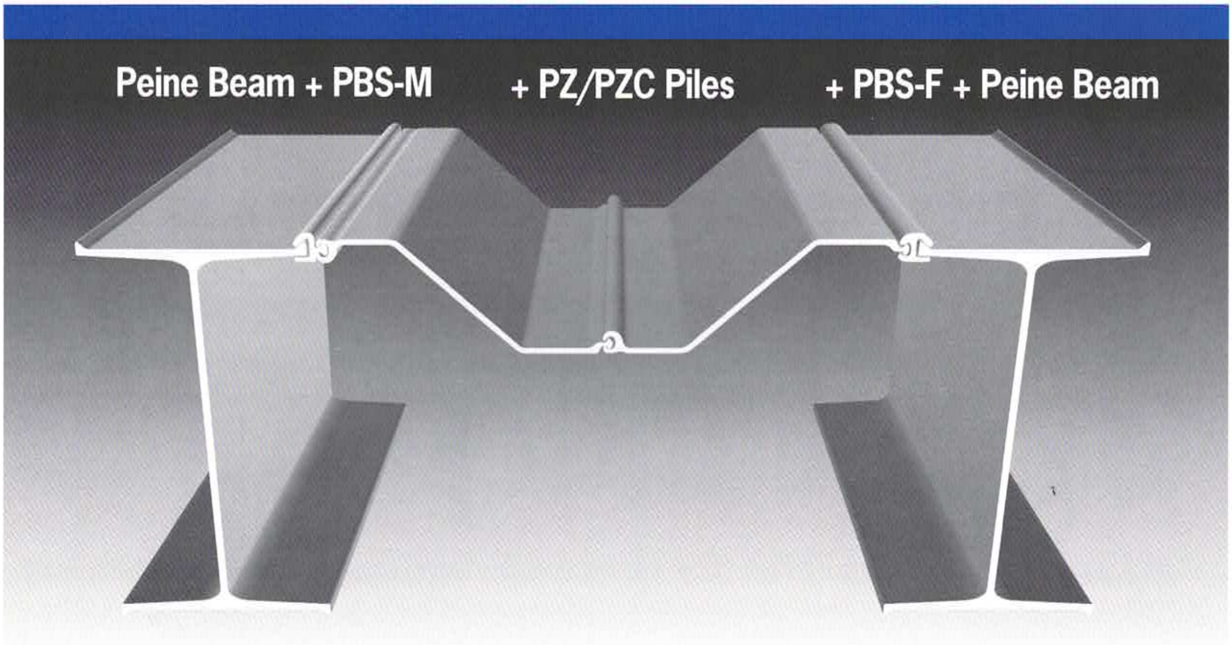


(Blue dashed lines indicate alternative configurations)

PZC-B High Section Modulus Systems

PZC-B systems are combinations of beams and PZC sheet piling designed to achieve higher section modulus requirements. The main load-carrying elements are the beams (Peine Beams, as shown below, or standard Wide Flange Beams). The intermediate sheet piling, along with extruded connectors, serves to close the face of the wall between the beams.





PZC-B System Advantages:

- Most efficient strength-to-weight solution for section modulus requirements over 70.7 in.^{3}/ft (3800 cm^3/m).
- Multiple configurations available to achieve desired section modulus and delivery.
- Beams can be driven deeper into dense soils than sheet piling.
- Sheet piling length is typically 60% to 80% of the length of beams.
- Flexibility of the Ball-and-Socket Interlock allows for easy setting of the intermediate sheet piling pair, while accommodating slight deviations inherent to the driving of the beams.
- Installed in less time than driving full-length heavy sheet piling in a continuous wall.

PZC-B Combined Wall System Installation:

- Install the beams first using a multi-level template
- Set and drive the intermediate sheet piling pairs between driven beams

The following table represents a limited overview of possible PZC-B combinations. Please refer to www.sheet-piling.com for an extensive solution list and complete details on other PZC-B combinations. This website also has tools available to estimate material requirements. For further assistance, please contact Chaparral directly.

Section	Solution Type	Section Modulus	Width	Weight* lbs/ft² (kg/m²)			Moment of Inertia	Nominal Coating Area in Panel Width**		Beam	Sheet	Connector
		in.^{3}/ft of wall (cm^3/m of wall)	in. (mm)	60%	80%	100%	in.^{4}/ lin. ft of wall (cm^4/ lin. m of wall)	Front Side ft²/ lin. ft of panel (m²/ lin. m of panel)	Front & Back Side ft²/ lin. ft of panel (m²/ lin. m of panel)			
PZC-B 37	I⌒I	69.6	69.3	32.8	36.9	41.0	1,144	6.94	20.95	W 33 X 118	PZC 13	BBS M&F
		3,740	1760	159.9	180.0	200.0	156,200	2.12	6.39			
PZC-B 51	I⌒I	95.1	76.0	36.0	39.8	43.6	1,685	7.76	24.16	PSp 900	PZC 13	PBS M&F
		5,110	1932	175.9	194.4	213.0	230,000	2.37	7.36			
PZC-B 57	I⌒I	106.5	69.8	41.4	45.5	49.6	1,925	6.99	21.60	W 36 X 170	PZC 13	BBS M&F
		5,720	1774	202.3	222.2	242.1	262,900	2.13	6.58			
PZC-B 68	I⌒I	126.2	76.0	40.8	44.6	48.4	2,494	7.76	24.75	PSp 1013	PZC 13	PBS M&F
		6,790	1932	199.1	217.7	236.3	340,600	2.37	7.54			
PZC-B 71	I⌒I	131.7	73.6	44.1	47.9	51.8	2,546	7.30	23.19	W 40 X 199	PZC 13	BBS M&F
		7,080	1868	215.2	234.0	252.9	347,600	2.23	7.07			
PZC-B 89	I⌒I	165.7	76.0	50.0	53.8	57.6	3,379	7.76	24.78	PSp 1035S	PZC 13	PBS M&F
		8,910	1932	244.2	262.8	281.4	461,500	2.37	7.55			
PZC-B 100	I⌒I	185.6	73.6	56.7	60.6	64.5	3,684	7.30	23.30	W 40 X 277	PZC 13	BBS M&F
		9,980	1871	277.0	295.9	314.7	503,000	2.23	7.10			
PZC-B 120	II⌒II	222.9	89.1	64.4	67.6	70.9	4,722	9.53	28.10	PSp 1016 Double	PZC 18	PBS M&F
		11,990	2263	314.4	330.3	346.1	644,900	2.90	8.56			
PZC-B 147	II⌒II	273.3	94.9	77.7	82.0	86.2	5,864	10.08	29.23	PSp 1035S Double	PZC 26	PBS M&F
		14,690	2410	379.6	400.3	421.0	800,800	3.07	8.91			

*Length of intermediate sheet piling sections as a percent of the beam's length.
**Excludes socket interior and ball of interlock.
NOTE: Section modulus calculation of the wall does not include the connectors interlocked with the sheet piling.

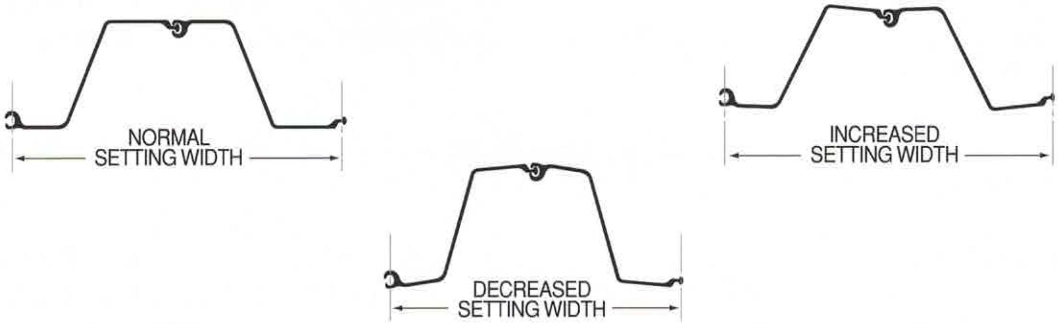
Setting and Driving Tips for Z-Profile Sheet Piling:

Improper setting and driving practices result in problems and costs that far out-weigh the initial expense of applying correct methods from the start. Although setting and driving techniques may vary according to the site conditions and/or the contractor's level of experience, several basic principles can be applied.

Use an adequate template – The utilization of an adequate steel template will facilitate the installation process and result in a superior end product. The purpose of the template is to both properly align the sheets during the setting process as well as to keep the sheets in alignment during the driving phase. Since a typical sheet weighs one ton or more, the template obviously needs to be of rugged construction. Also, bear in mind that the template will normally be used and moved multiple times at the job site; this is another reason for a well-designed and solidly constructed template.

Mark the template – To maintain the published laying width of the sheeting, it is very important to mark the template for each sheet, or pair of sheets. By following this procedure, the contractor can observe if the line being set is gaining or losing wall length. This procedure is important for installations such as: cofferdams, which must be closed; or anchored bulkheads, where tie-rod locations are critical. Depending upon the length of the sheets, the template might be one, or two – or more – tiers high. In order to maintain a plumb wall when driving sheets in excess of 50 feet (15 meters), a two-tier template is **always** suggested as a minimum.

Set a panel of piling – The length of the panel will vary depending upon site conditions, the contractor's experience, and other factors. In general, you might expect a panel length of 25 to 45 feet (8 to 14 meters). As each sheet, or pair of sheets, is set, the sheets may be rotated as necessary in the interlock (as shown below) in order to match the marks on the template.



Sheet piling supplied with the interlocks crimped or welded does not offer this advantage.

Keep the sheets plumb – It's of utmost importance that, as each pair is set, the sheets are plumb and secured before the next pair is set. Once the wall is allowed to get out of vertical alignment, the mistake will only get worse; and at some point the contractor will simply have to quit, extract the out of plumb sheets, and start over. The most important tool of the pile driving crew is a long level: 3 feet (1 meter) or more in length.

Set and drive with the ball-end leading – When the piles are set and driven with socket-end leading, the socket becomes clogged with soil and the ball must force the soil out of the opening. In some types of soils, such as very fine and dense sand, the resistance of the soil in the socket can be such that driving becomes impossible without damaging the sheets. Under such conditions – particularly with a vibratory hammer – it is possible to actually weld interlocks together.

If for some reason the sheets must be driven with the socket-end leading, such is the case when using an interlock sealant like WADIT, then place a bolt or some object in the socket at the bottom end to at least minimize clogging.

Drive the panel of sheets in stages – Piles driven full length in one operation are more prone to deflect and go off line. This is particularly true when the soil contains debris, boulders, or other obstructions. Subsequent piles are guided by the deflected section; and within a short length of wall, pile driving comes to a halt. The sheeting must then be pulled, and the wall has to be restarted.

The preferred process to minimize, if not eliminate, this problem is to first set a panel of sheets and then work the panel down as a unit. This is accomplished by driving the sheets (singles or paired), in increments using a defined sequence. The magnitude of the increment will be determined by the soil conditions. In general, the harder the driving, the less the driving increment – perhaps 6 feet (2 meters) in easy driving, versus 3 feet (1 meter), or less, in denser soil.

Panel driving allows the piles to be guided by previously driven piles, and it lessens the possibility of driving the piles out of interlock. During this phase, as during the setting process, it's important that constant attention be paid to maintaining a plumb wall. Any deviations from being plumb that are detected should be quickly corrected before things get out of hand.

Driving is ideally, and normally, accomplished by driving pairs. However, if driving becomes difficult due to obstructions or pockets of dense soil, simply drop back and drive single sheets. This is another advantage of not crimping or welding pairs.

Avoid splicing if possible – Randomly selecting Z-piles to splice could result in attempting to splice two cross sections together that do not match. This results in added time and costs.

If splicing is required, then the sheets should be ordered full length from the production mill. They should be cut and match-marked at the site. These sections can then be spliced back together to reconstruct the original sheet. This procedure reduces the mismatching of cross sections and improves section geometry match.

In order to avoid creating a plane of weakness in the wall, the splices on adjacent sheets must be staggered by a minimum of 3 feet (1 meter) or more, if feasible.

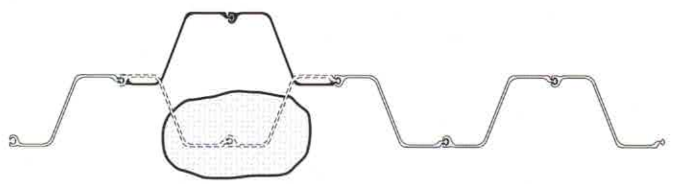
When splicing the pile, it's impossible to weld in the interlocks due to both the difficulty of welding in this area and the distortion caused by the heat from the welding. If full section modulus is required at the splice, it will be necessary to provide flange plates to make up for the loss of section modulus in the interlocks. Normal practice allows for a combination of butt-welding of the flanges and web, along with the addition of flange plates by fillet welding. Light "seal" welds around the perimeter of the interlocks will prevent the flow of water and soil through the splice.

Chaparral Ball & Socket Interlocks

Because ball and socket dimensions are the same for all Chaparral Z-Piling sections, all Chaparral Z-piling sections can interlock with each other. Also, because of the shape of the interlock, they can be joined in either of two arrangements:

The reversed interlock arrangement can be utilized to bypass obstructions when they are encountered along the driving line or to shift the driving line.

Normal Layout



Layout to Avoid an Obstruction

Layout to Shift the Line by the Depth of One Sheet

Another variation using reversed interlocks is shown below. It is useful when reduced section modulus is acceptable and the engineer wishes to reduce the weight per square feet of wall. In addition to the weight reduction, the laying width is increased, resulting in fewer interlocks and reduced installation time. Fewer interlocks per length of wall is important in a cutoff wall.

PS Sheet Piling

Chaparral produces PS *"Flat Sheet Piling"* sections with a thumb and finger interlock at our mill in Midlothian, Texas. These sections consist of a web with interlocks at each end. The interlocks are designed to resist high tensile loads, but the section has very little beam strength, i.e., section modulus. When properly interlocked, this three-point contact interlock system can withstand severe setting and driving conditions and still function as intended. Chaparral PS sections provide the highest swing to interlock strength ratios available. This enables a wide range of project designs, from small diameter cells to very large diameter cells.

Tensile Diagram For Properly Interlocked PS Sections

PS and Z-Piling sections should not be interlocked together. Chaparral PS 27.5 and PS 31 can be interlocked with each other but not with sections from another producer.

Cellular Construction Utilizing PS Sheet Piling

A cellular structure may be as simple as a single independent circular cell, or it could be a series of connected cells. The cell is constructed using an **even** number of PS 27.5 or PS 31 sheet piling sections.

How a Cell Functions:

Cellular design requires that the cells be founded on or in firm foundation material – and that the cells be filled with clean, free-draining granular material. The granular fill forces the sheets outward and places the cell wall into tension in the horizontal direction. The tension exerted on the wall is resisted by the high interlock strength of the PS sections.

A cell is normally designed to resist horizontal forces. In general it can be stated that the ability of a cell to resist horizontal forces increases as its diameter and height increases, usually in a one-to-one ratio. On the other hand, as the diameter and cell height increases, the required interlock strength of the PS sections also increases. Normal engineering practice is to limit the interlock load of PS sections to one-half the minimum ultimate interlock strength.

Two Types of Cellular Construction:

Closed Cells:

Single Cell Structures: Typically used in bridge abutments, shallow water docks, and mooring dolphins for securing barges. Cells can be used to protect bridge piers from barge or ship impacts.

Reinforced pier protection cell under construction on the Mystic River in East Boston, MA.

Continuous Closed Structures: Series of cells joined together with connecting arcs. Two types:

Permanent Structures:
- Deep Draft Bulkheads
- Graving Docks for construction of ships in the dry

Temporary Structures:
- Environmental remediation
- Cofferdams used in construction of locks and dams
- Repair of canal walls
- Construction of Hydroelectric facilities

Going from the Stage 1 cellular cofferdam to the Stage 2 cofferdam in order to complete a Lock & Dam.

Open Cells:

Open Cells are used primarily for docks and similar structures. Each cell's sheet pilings are driven in an arc, when viewed from above, with a vertical flat sheet pile membrane extending shoreward. The Open Cell bulkhead has several unique features:

- Does not need excessive toe embedment for stability, therefore requiring less driving time
- Significant time and financial savings utilizing this design versus traditional bulkhead designs
- The highest vertical load carrying capacity dock in the world
- Not settlement sensitive
- Wall heights up to 80 feet

A USCG open cell dock with 70 foot face sheets under construction in Unalaska, AK.

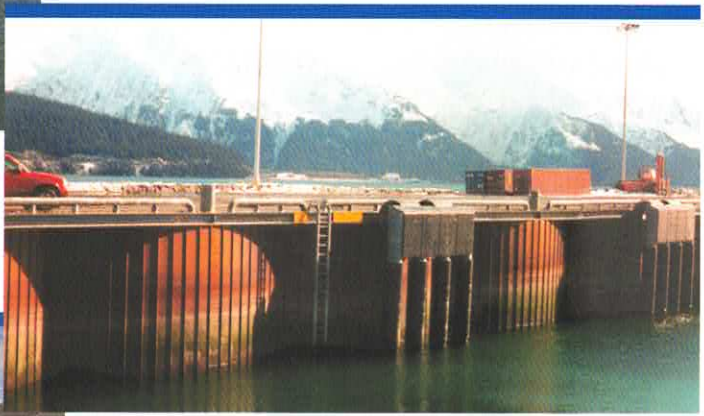
The design was developed and proven by PND Engineers, Inc. for extreme seismic conditions in Alaska. It is a proven design which has withstood high ice loading, large tide changes and corrosion factors. More than 140 projects have been installed.

More information on Open Cell Design can be found at www.pnd-anc.com or www.opencell.us

Cellular construction yields the following benefits:

- Provides a massive, self-sustaining structure that is safe and durable.
- Provides the highest load capacity structure.
- Can be installed by the average-size marine contractor without the need for unusually large equipment.
- Eliminates the need for construction and maintenance of slope protection and other disadvantages of open piling supported platforms because cells provide a solid-faced wharf.
- Eliminates many of the details of expensive and structurally vulnerable anchorage systems required for high-modulus, tied-back anchored walls.
- Provides long service life in marine environments, especially when augmented by modern corrosion protection methods.

Closed Cells,
Port of San Diego, California

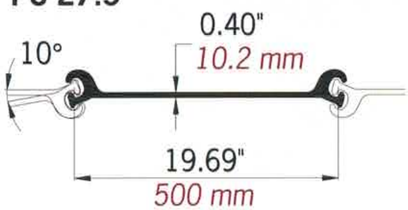


Open Cell Dock,
Seward, Alaska

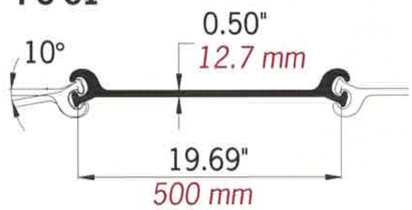
Open Cell Design

CHAPARRAL
PS (FLAT SHEET) PILING PROPERTIES

PS 27.5



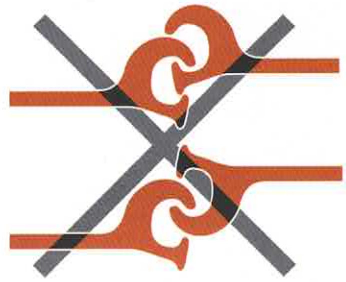
PS 31



Section	Nominal Width in. (mm)	Depth (Height) in. (mm)	Wall Depth (Height) in. (mm)	Web Thickness in. (mm)	Per Single Section: Area $in.^2$ (cm^2)	Per Single Section: Weight lbs/ft (kg/m)	Per Single Section: Moment of Inertia $in.^4$ (cm^4)	Per Single Section: Section Modulus $in.^3$ (cm^3)	Per Single Section: Total Surface Area ft^2/ft (m^2/m)	Per Single Section: Nominal Coating Area* ft^2/ft (m^2/m)	Per Unit of Wall: Area $in.^2/ft$ (cm^2/m)	Per Unit of Wall: Weight lbs/ft^2 (kg/m^2)	Per Unit of Wall: Moment of Inertia $in.^4/ft$ (cm^4/m)	Per Unit of Wall: Section Modulus $in.^3/ft$ (cm^3/m)
PS 27.5	19.69	2.83	3.55	0.40	13.26	45.1	5.0	3.2	4.50	3.64	8.08	27.5	3.0	1.9
	500	*72*	*90*	*10.2*	*85.5*	*67.1*	*207*	*52*	*1.37*	*1.11*	*171.0*	*134.2*	*414*	*103*
PS 31	19.69	2.83	3.55	0.50	14.96	50.9	5.0	3.2	4.50	3.64	9.11	31.0	3.0	1.9
	500	*72*	*90*	*12.7*	*96.5*	*75.7*	*207*	*52*	*1.37*	*1.11*	*192.9*	*151.4*	*414*	*103*

*Excludes interior of interlock.

Proper Interlock



Improper Interlock

Grade	Minimum Interlock Strength(1)	Minimum Swing(2)
A328	16 kips/in. (2,800 kN/m)	10 degrees
A572-50	20 kips/in. (3,500 kN/m)	10 degrees
A572-65	24 kips/in. (4,200 kN/m)	10 degrees

Higher interlock strengths are available but obtainable swing will be reduced in interlock strengths above 24 kips/in (4,200 kN/m).

NOTE: *INTERLOCKING OF CHAPARRAL PS SECTIONS WITH ANOTHER PRODUCER'S SECTION SHOULD NEVER BE CONSIDERED. PS and Z-Piling sections should not be interlocked together. Chaparral PS 27.5 and PS 31 can be interlocked with each other.*

(1) These minimum ultimate interlock strengths assume proper interlocking of sheets. To verify the strength of PS Sheet Piling, both yielding of the web and failure of the interlock should be considered.
(2) Swing reduces 1.5 degrees for each 10 feet (3 meters) in length over 70 feet (21 meters).

Connectors for PS Sheet Piling

Extruded connectors are suggested for Wye and Tee connections between cells. Consistent quality control during extrusion combined with ease of use and efficiency of construction make these engineered products superior to traditional fabricated sections. These connectors are readily available directly from the mill with PS sheet piling and can be ordered attached.

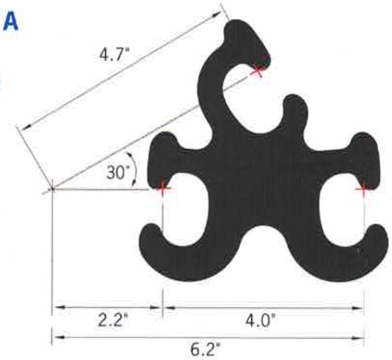
Advantages of extruded connectors are:

- Eliminates corrosion and structural concerns of welded connections.
- Uniform, consistent quality product.
- Faster product delivery – no delays waiting for fabricated sections.
- Easily transported, handled, stored and installed.
- SWC 120 is stocked with sheet piling.
- Swing or rotation is equal to the Chaparral PS Sheet Piling interlock.

Please go to page 20 and 21 of this handbook to view PS layouts using the SWC connectors. Please go to www.sheet-piling.com for orientation of connectors in cellular layouts.

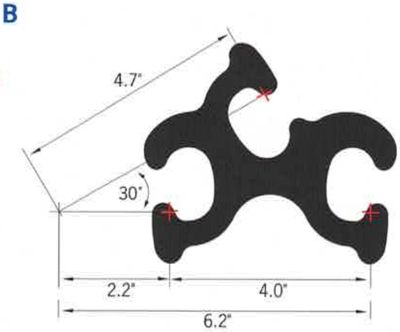
SWC 30 A

30° Wye



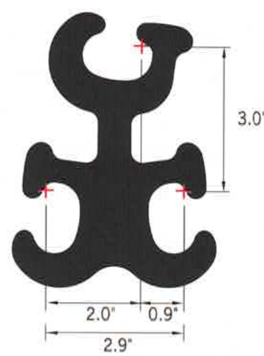
SWC 30 B

30° Wye



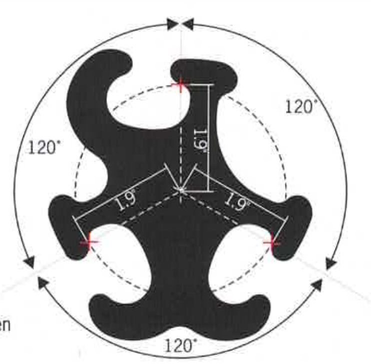
SWC 90 A

90° Tee



SWC 120

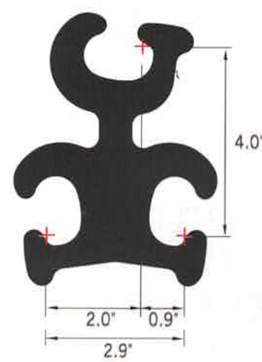
120° Wye



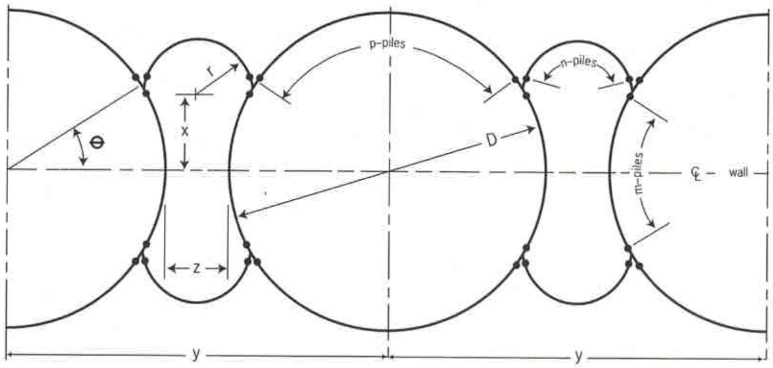
Wye Connector for Open Cell construction.

SWC 90 B

90° Tee



PS FLAT SHEET PILING 30° EXTRUDED WYE LAYOUT

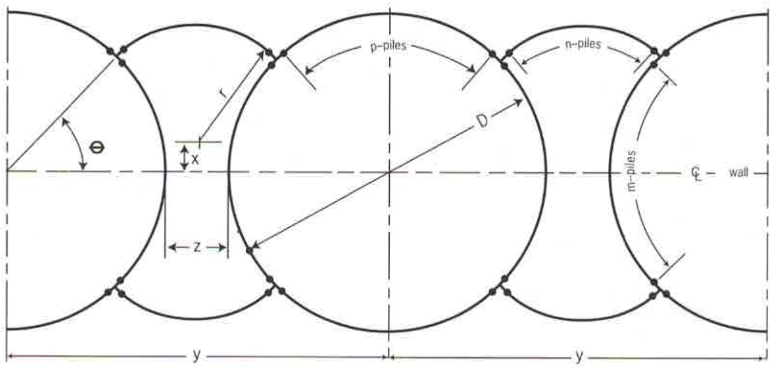


Θ is measured to the center of the 30° connection

Number of Piles in Cell†	D ft (m)	z ft (m)	y ft (m)	r ft (m)	X ft (m)	Θ deg	Number of Piles			Area		Average Width ft (m)	Layout Number (see Website)
							m	n	p	Within Circle sq ft (sq m)	Between Circles sq ft (sq m)		
78	39.07 *11.91*	12.88 *3.93*	51.96 *15.84*	9.1 *2.77*	9.88 *3.01*	31.8	13	17	24	1199 *111.4*	549 *51.0*	33.6 *10.2*	2
84	42.21 *12.87*	12.47 *3.80*	54.61 *16.65*	9.1 *2.77*	10.66 *3.25*	31.6	14	17	26	1399 *130.0*	566 *52.6*	35.9 *10.9*	1
90	45.34 *13.82*	14.14 *4.31*	59.48 *18.13*	10.15 *3.09*	11.45 *3.49*	31.5	15	19	30	1615 *150.0*	692 *64.3*	38.8 *11.8*	2
96	48.48 *14.78*	13.72 *4.18*	62.19 *18.96*	10.15 *3.09*	12.23 *3.73*	31.4	16	19	30	1846 *171.5*	711 *66.1*	41.1 *12.5*	1
102	51.61 *15.73*	15.39 *4.69*	67 *20.42*	11.19 *3.41*	13.01 *3.97*	30.2	17	21	32	2092 *194.4*	853 *79.2*	44 *13.4*	2
108	54.74 *16.68*	14.97 *4.56*	69.71 *21.25*	11.2 *3.41*	13.8 *4.21*	31.3	18	21	34	2354 *218.7*	873 *81.1*	46.3 *14.1*	1
114	57.88 *17.64*	16.64 *5.07*	74.51 *22.71*	12.24 *3.73*	14.58 *4.44*	31.2	19	23	36	2631 *244.4*	1029 *95.6*	49.1 *15.0*	2
120	61.01 *18.60*	16.22 *4.94*	77.23 *23.54*	12.24 *3.73*	15.36 *4.68*	31.1	20	23	38	2923 *271.6*	1051 *97.6*	51.5 *15.7*	1
126	64.14 *19.55*	17.89 *5.45*	82.03 *25.00*	13.28 *4.05*	16.15 *4.92*	31.1	21	25	40	3232 *300.3*	1222 *113.5*	54.3 *16.6*	2
132	67.28 *20.51*	19.56 *5.96*	86.83 *26.47*	14.33 *4.37*	16.93 *5.16*	31	22	27	42	3555 *330.3*	1406 *130.6*	57.1 *17.4*	1
138	70.41 *21.46*	19.14 *5.83*	89.55 *27.29*	14.33 *4.37*	17.71 *5.40*	31	23	27	44	3894 *361.8*	1432 *133.0*	59.5 *18.1*	2
144	73.55 *22.42*	20.81 *6.34*	94.35 *28.76*	15.37 *4.68*	18.5 *5.64*	31	24	29	46	4248 *394.7*	1631 *151.5*	62.3 *19.0*	1
150	76.68 *23.37*	20.39 *6.21*	97.07 *29.59*	15.37 *4.68*	19.28 *5.88*	30.9	25	29	48	4618 *429.0*	1657 *153.9*	64.6 *19.7*	2
156	79.81 *24.33*	22.06 *6.72*	101.87 *31.05*	16.42 *5.00*	20.06 *6.11*	30.9	26	31	50	5003 *464.8*	1871 *173.8*	67.5 *20.6*	1

Layout drawings showing the orientation of the extruded connections can be found at www.sheet-piling.com.
†Includes 4 extruded 30° Wye connectors

PS FLAT SHEET PILING 90° EXTRUDED TEE LAYOUT

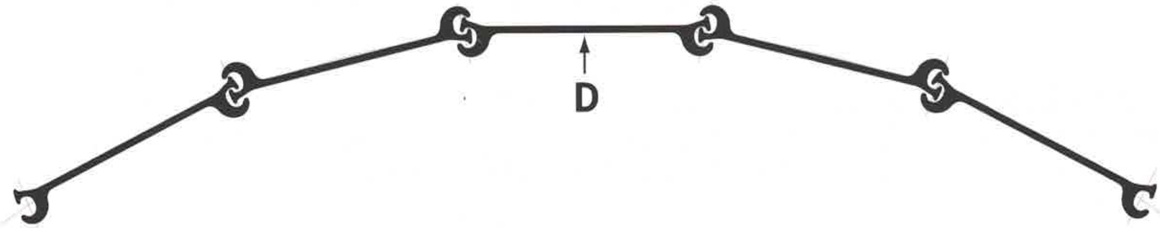


θ is measured to the center of the 90° connection

Number of Piles in Cell†	D ft (m)	z ft (m)	y ft (m)	r ft (m)	X ft (m)	θ deg	Number of Piles			Area		Average Width ft (m)	Layout Number (see Website)
							m	n	p	Within Circle sq ft (sq m)	Between Circles sq ft (sq m)		
44	21.20 6.46	7.53 2.30	28.73 8.76	9.72 2.96	0.68 0.21	45.3	10	9	10	353 32.8	197 18.3	19.2 5.9	4
48	23.29 7.10	6.84 2.08	30.13 9.18	9.67 2.95	1.45 0.44	45.2	11	9	11	426 39.6	203 18.9	20.9 6.4	6
52	25.38 7.74	6.31 1.92	31.69 9.66	9.73 2.97	2.15 0.66	45.2	12	9	12	506 47.0	210 19.5	22.6 6.9	4
56	27.47 8.37	5.62 1.71	33.09 10.09	9.68 2.95	2.92 0.89	45.2	13	9	13	593 55.1	213 19.8	24.3 7.4	6
60	29.56 9.01	5.09 1.55	34.64 10.56	9.73 2.97	3.62 1.10	45.2	14	9	14	686 63.7	218 20.3	26.1 8.0	4
64	31.65 9.65	5.95 1.81	37.60 11.46	10.76 3.28	3.58 1.09	45	15	10	15	787 73.1	264 24.5	27.9 8.5	3
68	33.73 10.28	5.42 1.65	39.15 11.93	10.82 3.30	4.28 1.30	45	16	10	16	894 83.1	269 25.0	29.7 9.1	5
72	35.82 10.92	4.73 1.44	40.55 12.36	10.76 3.28	5.05 1.54	45.2	17	10	17	1008 93.6	269 25.0	31.5 9.6	3
76	37.91 11.55	5.59 1.70	43.51 13.26	11.83 3.61	5.09 1.55	45.1	18	11	18	1129 104.9	324 30.1	33.4 10.2	4
80	40.00 12.19	4.91 1.50	44.91 13.69	11.77 3.59	5.87 1.79	45.1	19	11	19	1257 116.8	323 30.0	35.2 10.7	6
84	42.09 12.83	5.92 1.80	48.02 14.64	12.91 3.93	5.76 1.76	45	20	12	20	1391 129.2	386 35.9	37.0 11.3	5
88	44.18 13.47	5.24 1.60	49.42 15.06	12.85 3.92	6.53 1.99	45	21	12	21	1533 142.4	384 35.7	38.8 11.8	3
92	46.27 14.10	6.10 1.86	52.37 15.96	13.92 4.24	6.57 2.00	45.1	22	13	22	1681 156.2	450 41.8	40.7 12.4	4
96	48.36 14.74	5.42 1.65	53.77 16.39	13.86 4.22	7.34 2.24	45.1	23	13	23	1837 170.7	448 41.6	42.5 13.0	6
100	50.45 15.38	4.88 1.49	55.33 16.86	13.92 4.24	8.04 2.45	45.1	24	13	24	1999 185.7	451 41.9	44.3 13.5	4
104	52.54 16.01	5.74 1.75	58.28 17.76	14.94 4.55	8.01 2.44	45	25	14	25	2168 201.4	445 41.3	46.1 14.1	3
108	54.63 16.65	6.61 2.01	61.24 18.67	16.01 4.88	8.05 2.45	45.1	26	15	26	2344 217.8	596 55.4	48.0 14.6	4
112	56.72 17.29	5.92 1.80	62.64 19.09	15.95 4.86	8.82 2.69	45.1	27	15	27	2526 234.7	592 55.0	49.8 15.2	6
116	58.80 17.92	5.39 1.64	64.19 19.57	16.01 4.88	9.52 2.90	45.1	28	15	28	2716 252.3	595 55.3	51.6 15.7	4
120	60.89 18.56	6.25 1.91	67.14 20.46	17.03 5.19	9.49 2.89	45	29	16	29	2912 270.5	674 62.6	53.4 16.3	3
124	62.98 19.20	5.71 1.74	68.7 20.94	17.08 5.21	10.19 3.11	45	30	16	30	3116 289.5	677 62.9	55.2 16.8	5
128	65.07 19.83	5.03 1.53	70.1 21.37	17.03 5.19	10.96 3.34	45	31	16	31	3326 309.0	670 62.2	57.0 17.4	3

Layout drawings showing the orientation of the extruded connections can be found at www.sheet-piling.com.
†Includes 4 extruded 90° Tee connectors

DIAMETERS AND AREAS OF CIRCULAR CELLS USING PS 27.5 AND PS 31



Number of Pieces	PS 27.5 & PS 31 D ft	PS 27.5 & PS 31 Area ft²	Required Swing deg	Theoretical Bend deg θ	Suggested Bend deg θ
12	6.27	31	30.0	20.0	25.0
14	7.31	42	25.7	15.7	25.0
16	8.36	55	22.5	12.5	20.0
18	9.40	69	20.0	10.0	15.0
20	10.45	86	18.0	8.0	15.0
22	11.49	104	16.4	6.4	15.0
24	12.53	123	15.0	5.0	10.0
26	13.58	145	13.8	3.6	10.0
28	14.62	168	12.9	2.9	10.0
30	15.67	193	12.0	2.0	10.0
32	16.71	219	11.3	1.3	10.0
34	17.76	248	10.6	0.6	10.0
36	18.80	278	10.0		
38	19.85	309	9.5		
40	20.89	343	9.0		
42	21.94	378	8.6		
44	22.98	415	8.2		
46	24.03	453	7.8		
48	25.07	494	7.5		
50	26.11	536	7.2		
52	27.16	579	6.9		
54	28.20	625	6.7		
56	29.25	672	6.4		
58	30.29	721	6.2		
60	31.34	771	6.0		
62	32.38	824	5.8		
64	33.43	878	5.6		
66	34.47	933	5.5		
68	35,52	999	5.3		
70	36.56	1050	5.1		
72	37.61	1111	5.0		
74	36.65	1173	4.9		
76	39.69	1238	4.7		
78	40.74	1304	4.6		
80	41.78	1371	4.5		
82	42.38	1441	4.4		
84	43.87	1512	4.3		
86	44.92	1585	4.2		
88	45.96	1659	4.1		
90	47.01	1736	4.0		
92	48.05	1813	3.9		
94	49.10	1893	3.8		
96	50.14	1975	3.8		
98	51.18	2057	3.7		
100	52.23	2143	3.6		

Small cells constructed with bent web piles must have half of the piles bent with fingers inside and half with fingers outside.

PS 27.5 and PS 31 when properly interlocked, are designed to provide a swing up to 10 degrees (in either direction) for lengths up to 70 feet (21 meters). The ability to obtain a full 10 degrees swing decreases with length because of the difficulty in handling the longer pieces. For lengths over 70 feet (21 meters), it is necessary to anticipate a reduction in obtainable swing of 1.5 degrees for each 10 feet (3 meters) increase in length.

Setting and Driving Tips for PS Flat Sheets in Closed Cells:

Although setting and driving techniques vary with the individual contractor and site conditions, several basic principles can generally be applied. It should be realized that the lack of good setting and driving practices can result in job delays and an unsatisfactory structure. The following suggestions are offered to help avoid problems at the site:

Handling of PS sections. These sections have very little modulus (beam strength) and are, therefore, very susceptible to handling damage. It is important that great care be taken when transporting or lifting these sections. When sheets exceed 70 feet in length, they should be lifted at two or more points.

Have an adequate steel template. Longer sheeting lengths will require a two or three tier template with tiers spaced 15 feet (4.5 meters) or more apart. For example, a contractor should consider at least a two tier template when installing 70 foot (21 meters) or longer sheets as this will facilitate setting and driving and result in a superior end product. As with Z-Piling, it is important that each sheet be plumbed and secured when set.

The diameter of the template is predicated on the contractor's experience and method of setting circular cells. It is important that the template diameter be less than the theoretical cell diameter in order to easily close the cell. Upon filling, the finished cell will expand to meet or exceed published values.

When a cell with long lengths is being constructed, it may be advisable to stiffen the starter sheet by reinforcing it full length with a structural shape. Site conditions such as swift water or hard driving may require more sheets to be reinforced.

Splicing of PS sections. When it is necessary to splice PS sections the splice point on adjacent sheets should be staggered by several feet.

Mark the driving template for each pile or pair of piles. This allows for wall adjustments to be made during the setting phase, insuring that the sheets are located properly for cell closure.

Insure that the sheets are properly interlocked when set. Improper interlocks become the "weak links" and result in job delays and/or failures.

Set all sheets in the cell before driving any of the sheets, other than nominal pinning of the starter sheet(s).

"Shake out" several sheets at any closure point. Following good practice as noted above should ideally result in the last sheet sliding smoothly down into the remaining gap. Although the first sheet is set plumb and the next to last sheet is plumb, the chances that the remaining gap is uniform (19.69 inches) the full length is improbable. Picking up and dropping, or "shaking out," several sheets near the closure point until the sheets run smoothly will minimize the chance of driving sheets out of interlock.

Drive piles in pairs. Once sheet piles are threaded and set, it is more economical to drive two at a time. (Some experts suggest that the energy needed to drive a pair may be only 50% more than that required to drive a single pile.)

Drive piles in stages and work around the entire cell by alternating sheets (pairs). This allows the piles to be guided by those previously driven, and lessens the chance of driving sheets out of interlock. The distance a pile, or pair of piles, should be driven at any one time will be governed by the driving conditions. In the first pass around the cell, every other pair is driven perhaps 4 feet. In the second pass around the cell, the un-driven pairs are driven 8 feet, 4 feet restrained by the adjacent pairs and then 4 feet into virgin soil. This procedure is continued until the cell is driven to design tip elevation. Good practice, in order to keep the cell plumb, is to reverse the direction of driving for each pass around the cell.

Corrosion

Introduction

It is not uncommon for an engineer designing a steel sheet piling structure to have concerns about corrosion. In most cases, the concerns can be satisfied. The following discussion will give an engineer some guidance in accessing possible corrosion potential in various environments – soil, fresh water, and salt water. There is also discussion on possible protective measures when corrosion protection must be employed.

Durability of Steel Piles

IN SOIL: In 1959 the National Bureau of Standards (NBS)* initiated a research program to investigate the corrosion of steel piles driven into soil. This effort was under the direction of Melvin Romanoff, a longtime corrosion researcher who was well known for his research in pipeline corrosion.

In 1962, Melvin Romanoff authored NBS Monograph 58, entitled "Corrosion of Steel Pilings in Soils." The following excerpts are taken from his summary.

> *"Steel pilings which have been in service in various underground structures for periods ranging between 7 and 40 years were inspected by pulling piles at 8 locations and making excavations to expose pile sections at 11 locations. The conditions at the sites varied widely, as indicated by the soil types which ranged from well-drained sands to impervious clays, soil resistivities which ranged from 300 ohm-cm to 50,200 ohm-cm and soil pH which ranged from 2.3 to 8.6."*

> *"The data indicate that the type and amount of corrosion observed on the steel pilings driven into undisturbed natural soils, regardless of the soil characteristics and properties, is not sufficient to significantly affect the strength or useful life of pilings as load-bearing structures."*

> *"...The data indicate that undisturbed soils are so deficient in oxygen at levels a few feet (1 meter) below the ground line or below the water table zone, that steel pilings are not appreciably affected by corrosion, regardless of the soil types or the soil properties. Properties of soils such as type, drainage, resistivity, pH or chemical composition are of no practical value in determining the corrosiveness of soils toward steel pilings driven underground. This is contrary to everything previously published pertaining to the behavior of steel under disturbed soil conditions. Hence, it can be concluded that National Bureau of Standards data previously published on specimens exposed in disturbed soils do not apply to steel pilings which are driven in undisturbed soils."*

**Now named the National Institute of Standards and Technology (NIST)*

(Corrosion continued)

Romanoff continued his research through the 60's. In 1969 he presented a paper at the 25th Conference of the National Association of Corrosion Engineers (NACE). This paper was based on corrosion data from 25 piles with exposures from 8 to 50 years in a wider variety of soil environments and different geographic locations than those covered in Monograph 58.

In this second report Romanoff concluded:

> *"The observations reported in this paper are in agreement and substantiate the observations and conclusions based on the results of the previous examinations on steel pile structures which are published in NBS Monograph 58."*

Mr. Romanoff initiated research on corrosion of steel piling driven into disturbed soils in 1966. This research resulted in NBS Monograph 128, entitled "Corrosion Rates on Underground Steel Test Piles at Turcot Yard, Montreal," which he co-authored with W.J. Schwerdtfeger. In recent years, research on corrosion of steel piling driven into disturbed soils and "dirty" fills has been sponsored by the National Cooperative Highway Research Program (NCHRP).

Additional information on these subjects can be found at the NACE website at www.NACE.org.

IN UNPOLLUTED FRESH WATER: There is very little published data regarding the corrosion of steel piling in unpolluted fresh water. This lack of data is explained by the general absence of significant corrosion of steel piling structures located in fresh water.

Two examples of sheet piling structures with long life are located in New York:

- A bulkhead at Black Rock in Buffalo, NY. This dock was constructed in 1910.
- A bulkhead near Albany, NY which was constructed in 1929.

IN A MARINE ENVIRONMENT: The use of steel piles in marine environments is common, and the questions of corrosion and appropriate methods of protection merit serious consideration. The life of unprotected steel piling in sea-water installations varies with the conditions of exposure. Structures located in protected harbors can be expected to have a considerably longer life than shore structures which are subject to salt spray, wave action, and sand abrasion.

Coatings and cathodic protection are two methods commonly used to prevent current flow and protect sheet piling installations. Unprotected steel in sea water corrodes by an electrochemical process. Sea water having a low electrical resistance functions as the electrolyte. Certain areas of the steel are anodic, and current flows from them through the sea water to cathodic areas. The circuit is completed through the metal. Corrosion occurs only at the anodic areas and, if the flow of current is prevented, corrosion cannot occur.

(Corrosion continued)

The most severe corrosion will occur in the splash zone. In this zone, rust films have little opportunity to become dry and, therefore, do not develop protective properties. Corrosion in this area is further aggravated by oxygen in the air and the fact that the splashing sea water has high oxygen content. Corrosion rates increase with increasing oxygen concentrations. If the water is shallow and the structure is subjected to breaking waves, the removal of corrosion products by sand particles in the water may significantly accelerate the corrosion rate. In the tidal zone, the corrosion may be minimal. The corrosion may increase from mean low tide down one or two feet (0.3 or 0.6 meters) into the submerged zone. The rate of corrosion decreases rapidly with water depth and is comparatively low at depths greater than two feet (0.6 meters) below the low-water level. In some cases, there is an increase at the mud line, not usually serious. If the structure is located in a shallow tidal estuary, the movement of sand at the mud line may continually blast-clean the steel at that point. Protective measures must be taken to control the corrosion/erosion effects encountered in such locations.

Protective coatings

The most common method of protecting steel piling against corrosion is through the use of coatings, such as a coal tar epoxy system. It is important when coating steel that the steel surface be grit blasted to near white or white as specified by the paint manufacturer. A common coating system is 16 mils of coal tar epoxy. For additional coating life, a designer might consider an organic zinc rich primer.

To be effective, a coating must cover the splash zone, the tidal zone, and extend several feet below low water. Generally the coating is extended to a depth five feet (1.5 meters) below mean low water. Below that point, the steel is completely submerged and the oxygen content greatly lowered. Therefore, corrosion will usually proceed at a much reduced rate. The decision of whether to extend the coating through the submerged zone to a few feet (1 meter) below the dredge line usually depends upon the design life of the structure. For economy and closer control of quality, the coatings should be applied in a shop by an experienced applicator.

For best long term durability and appearance of the sheet piling sections at the interlocked joint, it is recommended the sheets be coated as single pieces, rather than pairs. By coating single sections, a better coated system will be obtained in the joint area.

It is sometimes suggested in the literature that the solution to corrosion is the use of thicker steel. From the above discussion it should be understood that the most severe corrosion occurs in a relatively small zone of the piling which is usually not highly stressed (the area is lightly loaded). Using thicker steel to protect a relatively short length of the piling results in an increased total piling weight which escalates costs. It makes better economical sense to protect the critical corrosion zone with a good coating system applied to a properly prepared steel surface.

(Corrosion continued)

Concrete jacketing of steel piling has been used and can be very effective. In shallow water, complete encasement of the submerged portion will offer excellent protection. Designers should exercise caution, however, when designing partial jackets because a corrosion cell may form at the steel-concrete interface. This could result in an increased rate of corrosion on the unencased, bare steel adjacent to the concrete jacket. To prevent or minimize the formation of such a cell, the designer should consider insulating the steel from the concrete. This may be accomplished by the application of a coating extending approximately one foot (0.3 meters) each side of the interface. Dense concrete should be used, and any steel reinforcement should have a minimum cover of 4 inches (10 centimeters).

Cathodic Protection:

An effective method of corrosion control for continually submerged steel is cathodic protection. As discussed previously, unprotected bare steel in sea water corrodes at the anodic areas of the pile. Simply put, cathodic protection is a corrosion control method which makes the steel pile the cathode of an external electrochemical cell. Sufficient current is applied to the steel pile from an external source to eliminate anodic areas on the steel. The direct current source can be either a rectifier or sacrificial anodes suspended in the water.

A properly designed, installed, and maintained cathodic protection system effectively prevents corrosion in the submerged zone. It is, however, only partially effective in the tidal zone and provides no protection in the splash zone. Therefore, a cathodically protected structure would have to be protected in the tidal and splash zones by some other method such as a coating system. Coating the submerged zone is suggested since this will reduce the power requirements for the system.

Since the corrosion rate of steel decreases rapidly with depth below mean low water, the need for cathodic protection is often uncertain in the design stage. Therefore, it is good practice to connect the piles electrically during construction. Then, if the need for the system is determined by later inspection of the structure, it can be completed conveniently.

Additional information on these subjects can be found at the NACE website at www.NACE.org.

(Corrosion continued)

Corrosion Resisting Steels

Chaparral Steel piling products are also available in ASTM Grades A588 and A690. ***It should be noted current scrap based steel production is typically more corrosion resistant than those originally produced from virgin ores.***

Most corrosion resistant steels contain additions of both chromium and copper, and may also contain additions of silicon, nickel, phosphorous, or other alloying elements which enhance atmospheric corrosion resistance. Based on corrosion studies, A588 and A690 behave in a similar manner to carbon structural steels with respect to corrosion when submerged in water or driven in soil.

ASTM A588 (or A709 – 50W), sometimes referred to in the industry as "COR-TEN," is a high strength, low alloy (HSLA) atmospheric weathering steel containing specified levels of copper, chromium, and may contain nickel at levels greater than typical carbon structural steels.

The chemical composition of this grade provides enhanced atmospheric corrosion resistance when exposed in an appropriate atmospheric environment. This increased resistance is due to the formation of a tightly adherent oxide coating that acts as a barrier to further atmospheric corrosion. This tight oxide is best developed when the steel is exposed to frequent wet-dry cycles, such as from rain or dew. Exposures to be avoided, or viewed with caution, are industrial sites with corrosive fumes and areas along the coasts where there will be exposure to salt water spray or salt laden fog.

This steel grade is best utilized, in the proper environment, where aesthetics are important and the tight, dense brown oxide coating on the bare steel will provide a pleasing appearance.

ASTM A690, sometimes referred to in the industry as "Mariner," is a high strength, low alloy (HSLA) rephosphorized steel developed for use in Marine environments. This steel also contains higher levels of nickel and copper than typical carbon structural steel and Grade A588. It exhibits substantially greater corrosion resistance to salt water corrosion in the splash zone of exposed marine structures than typical carbon structural steels.

Specifications

CHAPARRAL Steel Grades for PZC, PZ, and PS Profiles

North American Grades		
ASTM	Yield Strength	
	(ksi)	(MPa)
A 328	39	270
A 572 Grade 50	50	345
A 572 Grade 60	60	415
A 572 Grade 65	65	450
A 588*	50	345
A 690**	50	345

European Grades		
EN 10248	Yield Strength	
	(ksi)	(MPa)
S 240 GP	35	240
S 270 GP	39	270
S 355 GP	51	355
S 430 GP	62	430
S 450 GP	65	450

*A588 contains specified levels of Cu, Cr, and Ni.

**A690 contains specified levels of Ni, Cu, and P at higher levels than the other listed grades on the table.

A572 Grade 50 and S 355 GP are the most economical and readily available grades. Inquire for minimum order requirements for other grades.

S 240 GP, S 270 GP, and S 355 GP Z-profiles can be supplied for European projects requiring the ÜHP proof of conformity.

Chaparral Sheet Piling Grades and their Chemistries

	ASTM A328	ASTM A572-50	ASTM A572-60	ASTM A572-65	ASTM A588 A**	ASTM A690
C %	***	0.23 max	0.26 max	0.23 max	0.19 max	0.22 max
Mn %	***	1.35 maxA	1.35 maxA	1.65 maxB	0.80 - 1.25	0.60 - 0.90C
P %	0.035 max	0.04 max	0.04 max	0.04 max	0.04 max	0.08 - 0.15
S %	0.04 max	0.05 max	0.05 max	0.05 max	0.05 max	0.04 max
Si %	***	0.40 max	0.40 max	0.40 max	0.30 - 0.65	0.40 max
Cu %	***	***	***	***	0.25 - 0.40	0.50 min
Ni %	***	***	***	***	0.40 max	0.40 - 0.75
Cr %	***	***	***	***	0.40 - 0.65	***
Mo %	***	***	***	***	***	***
Sn %	***	***	***	***	***	***
V %	***	0.010 - 0.15*	0.010 - 0.15*	0.010 - 0.15*	0.02 - 0.10	***
Cb / Nb %	***	0.005 - 0.05*	0.005 - 0.05*	0.005 - 0.05*	n/a	***
Yield ksi [MPa]	39 min [270]	50 min [345]	60 min [415]	65 min [450]	50 min [345]	50 min [345]
Tensile ksi [MPa]	70 min [485]	65 min [450]	75 min [520]	80 min [550]	70 min [485]	70 min [485]
Elong %	18 @ 8 in.	18 @ 8 in.	16 @ 8 in.	15 @ 8 in.	18 @ 8 in.	18 @ 8 in.

*would contain singly or in combination, dependent on production type (1, 2 or 3)

**other variations of ASTM A588 are available such as A588 B, A588 C, etc.

***= not specified (Where ***is shown for copper a minimum of 0.20 may be specified).

(A) For each reduction of 0.01% below C maximum, an increase of 0.06% Mn above specified maximum is permitted, up to a maximum of 1.50%.

(B) For material with thickness of 1/2" (13mm) or less, Mn maximum of 1.35% would apply when C is greater than 0.21%.

(C) For each reduction of 0.01% below C maximum, an increase of 0.06% Mn above specified maximum is permitted, up to a maximum of 1.10%.

Mechanical Testing

Tensile tests are performed in accordance with ASTM A6 and A370 or EN 10248.

In addition to the standard tensile test, a minimum of two interlock strength tests are performed for each heat of PS sections.

Tolerances

When using steel sheet piling it is necessary to make allowances for deviations from theoretical exactness. The basic character of the rolling processes and normal limitations of mill equipment limit the degree of precision obtainable in the production of steel sheet piling. Therefore, care must be taken during installation to assure that each pair of sheets is being set at the desired driving dimensions.

Interlocks should be continuous, reasonably free-sliding to grade when threaded, and for PS sections should have sufficient clearance to allow piles to be swung within the stated limits.

All steel sheet piling has an allowable weight variation of ± 2.5% and are invoiced on theoretical weight. Length tolerance is minus 0 inches (0 centimeters) and plus 5 inches (12.7 centimeters).

Lengths

Sheet piling sections are rolled and cut to ordered length. For best economy, the designer should specify the actual length as calculated in the design process. Stock lengths are typically available in 5 feet (1.5 meters) increments.

All sections are readily available in lengths up to 70 feet (21 meters) from regular rollings. Chaparral can supply longer lengths, sometimes in excess of 100 feet (30 meters). Before ordering lengths exceeding 70 feet (21 meters) check for availability by calling our **Piling Sales Office at 800-527-7979**.

Splicing:

If possible, splicing of Z-piling sections should be avoided. If splicing is necessary, sections should be ordered full length from the mill. They should be match-marked and cut at the jobsite. These match-marked sections should then be spliced together. This procedure improves section geometry match-up. Splicing of random sheets could result in setting and driving difficulties.

Handling Holes

Z-Piling: Paired sections will have one handling hole in both sections, with both holes at the same end of the pair upon request.

PS Piling: Each piece can be provided with one handling hole at one end upon request.

Swing

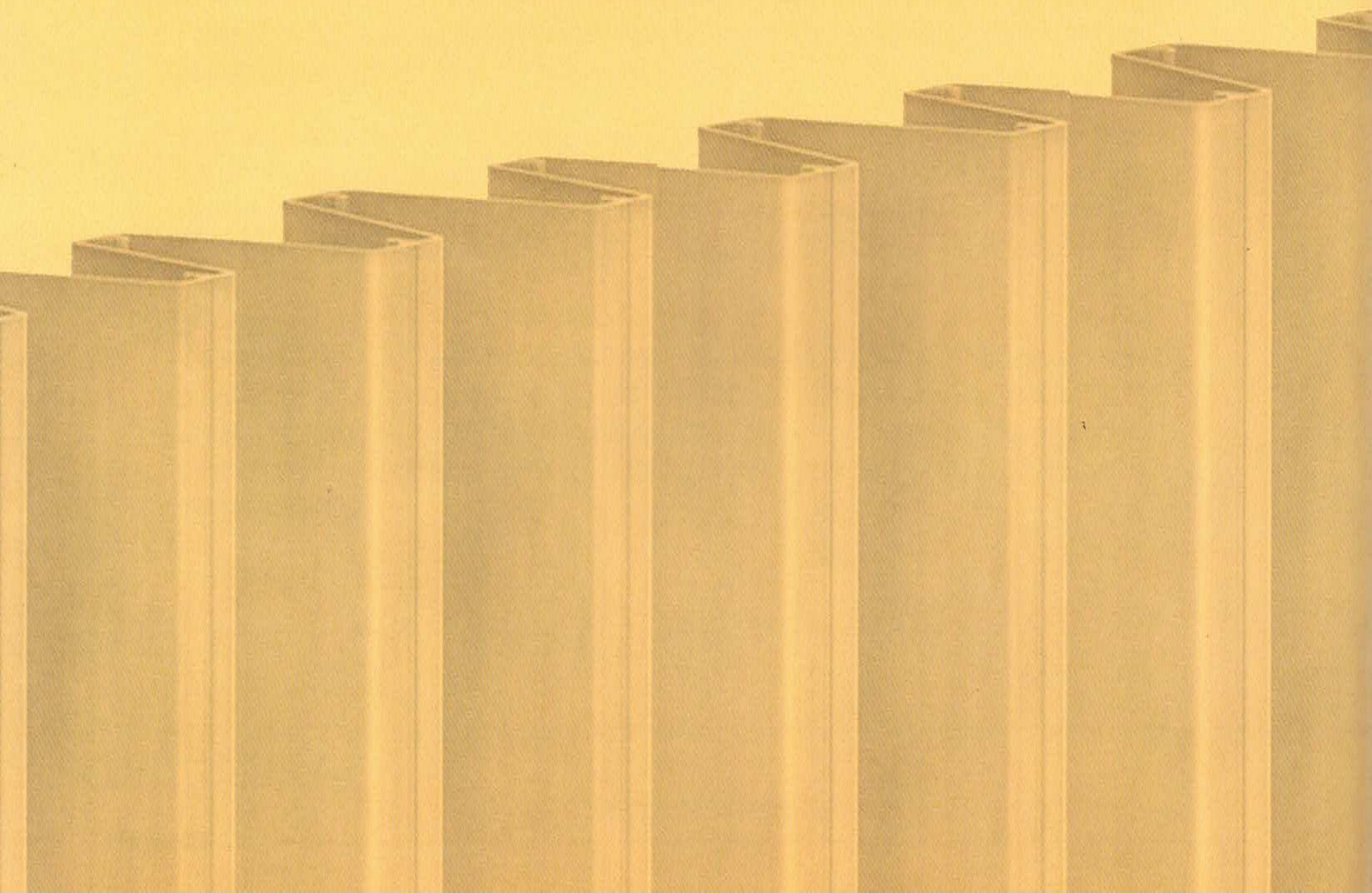
The ability to obtain swing (rotation) between two properly interlocked sections will decrease with increasing length of the sheets. This is due to the fact that as the lengths becomes longer, and handling becomes more difficult, straightness becomes more of a factor.

Z-Piling: Chaparral does not publish a swing value for Z-sections. As a "rule of thumb" it might be assumed that a 40 foot (12 meters) length would obtain a swing of up to 5 degrees.

PS Piling: The Chaparral PS sections with interlock strengths up to 24 kips per inch (4,200 kN/m) are designed to have a minimum swing of 10 degrees in either direction on lengths up to 70 feet (21 meters). With longer lengths it is necessary to anticipate a reduction in obtainable swing of 1.5 degrees for each 10 feet (3 meters) in length over 70 feet (21 meters).

Chaparral appreciates
the continued support
and consideration of our
piling products
throughout the world.

For additional copies of this
Handbook, please go to
www.sheet-piling.com.



Transportation

Environmental


Marine


Foundation

CHAPARRAL

300 Ward Road

Midlothian, Texas 76065

USA

972.775.8241

800.527.7979

www.sheet-piling.com