

Designing with Aluminum Sheet Piling



A Whitepaper by:

Ben Brown

Physical properties are defined by ASTM testing standards, The Aluminum Association Design Manual, The Naval Facilities Design Manual DM 7.2, The US Army Corps of Engineers General Design Guide: PVC Sheet Pile and/or standard engineering practice. The values shown are nominal and may vary. The information found in this document is believed to be true and accurate. No warranties of any kind are made as to the suitability of any CMI product for particular applications or the results obtained there from. Crane Materials International is a Crane Building Products® company. ShoreGuard®, The ShoreGuard Seawall System™, C-Loc®, TimberGuard®, GeoGuard®, Dura Dock®, Shore-All®, GatorGates®, GatorDock Elite™, ArmorWare™, ArmorRod™, Box Profile™, UltraComposite™, Elite Wall™, Elite Panel™, Elite Fascia Panel™, Flat Panel™, XCR™, XCR Technology™, XCR Vinyl™, GatorBridge™, Gator Aluminum™, Gator Sheet Piling™, GatorDock™, I-Beam Lock™, Textured Slate™, Crane Materials International™ logo, CMI Sheet Piling Solutions™, Aqua Terra System™, Endurance™, Endurance CSP™, Polaris™, Eclipse™, GridSpine™, 21 Poly™, PileClaw™, SheerScape™, SheerScape Retaining Wall Systems™, Sheer Panel™ and CMI Waterfront Solutions™ are trademarks, service marks or trade names of Crane Materials International. United States and International Patent numbers 4,674,921; 4,690,588; 5,292,208; 5,145,287; 6,000,883; 6,033,155; 6,053,666; D420,154; 6,575,667; 7,059,807; 7,056,066; 7,025,539; 7,393,482; 5,503,503; 5,803,672; 6,231,271; 1,245,061CA and other patents pending. © 2011 Crane Materials International. All Rights Reserved.

Aluminum offers the familiarity and comfort of a structural metal, and corrosion and weatherability characteristics superior to those of steel or wood. Aluminum has a very high strength-to-weight ratio, higher than most other metals and 3-5 times that of steel, making it cost effective and easy to handle on the job site. These characteristics explain why aluminum is the material of choice in the aviation and automotive industries. In addition, aluminum exhibits excellent corrosion resistance, illustrated by its dominance in food packaging and marine applications. The marine environment delivers excessively harsh and corrosive conditions, making aluminum a top performer as a sheet pile material.

As for all load bearing structures, it is important that proper techniques are followed when designing an aluminum sheet pile wall. This paper will aid the designer in establishing the proper criteria for aluminum sheet pile selection and application.

Using the right Alloy and Temper

There are over 100 variations of aluminum alloys and tempers commercially available, each with its unique strengths and weaknesses. In its pure form, aluminum is a soft and relatively weak material that would struggle to perform in modern industrial applications. The first step towards achieving high structural performance is the addition of small amounts of other elements, which dramatically impact aluminum's strength. This process is known as alloying, and the resulting blend is designated with a 4-digit identifier based on the alloying elements. Although aluminum is renowned for its excellent corrosion resistance, many alloys have been developed for specific applications where corrosion is a secondary or non-issue and have correspondingly poor corrosion fighting abilities. Alloy selection can drastically affect corrosion characteristics and it is imperative that the appropriate alloy be selected to perform as expected in the field. For marine applications, the 6000 series

provides the best combination of low cost, excellent corrosion resistance, and strength. The second step in achieving higher structural performance is a process known as tempering. For the most common structural alloys, this is a heat treatment that further increases the material's strength. This process is designated by a 2-digit identifier that follows the alloy designation based on the type and number of tempering stages. CMI selects the most suitable alloy and temper for load bearing structures in the marine environment, 6061-T6, for use in all its aluminum sheet piling.

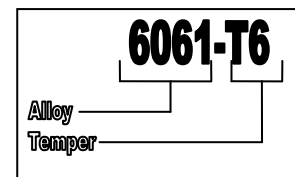


Figure 1
Alloy and temper designation

Design Values

When designing a sheet pile wall, two characteristics, shape properties and material properties, are used to calculate an appropriate sheet for a project. First, it is necessary to establish the values needed for design.

Establishing the Moment of Inertia (I)

A body's moment of inertia is a geometric property of its cross section, used to predict its resistance to bending and deflection. Depending on the specific shape of this cross section, calculation can be very complicated and difficult. Most CAD programs today include a feature that can calculate this value for a given profile, but it is important to understand what is involved and about which axis the shape's moment of inertia is calculated. Since sheet piling varies in width, the moment of inertia is generally described per running foot of wall for an apples-to-apples comparison.

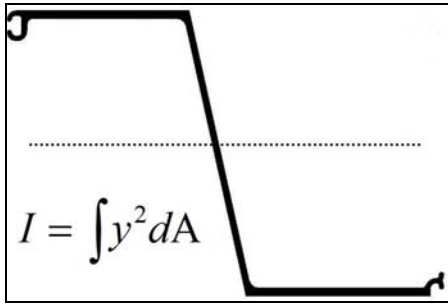


Figure 2
Moment of Inertia about the centroid

Establishing Section Modulus (Z)

For bending moment calculations, a sheet’s shape properties are determined solely by the geometry of the profile and combined into one design value, section modulus. Section modulus is defined below, where **Z** is section modulus, **I** is the shape’s moment of inertia, and **y** is the distance from the outer face to the neutral axis (typically approximated by ½ the section depth for sheet piling).

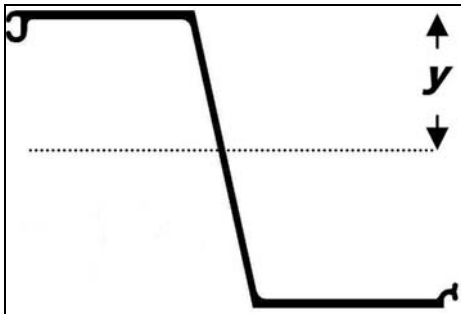
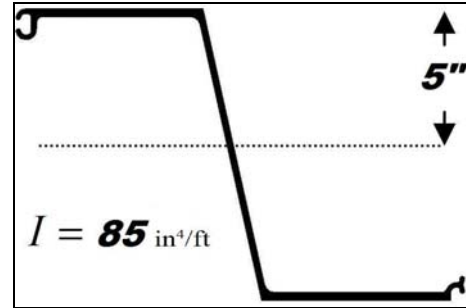


Figure 3
y value

$$Z = \frac{I}{y}$$

Equation 1
Section Modulus

A section modulus of **17.0 (in³/ft)** is predicted for PZH-159, a heavy duty sheet offered by CMI.



$$Z = \frac{85 \text{ (in}^4 / \text{ft)}}{5 \text{ (in)}} = 17.0 \text{ (in}^3 / \text{ft)}$$

Example 1
Section Modulus calculation for PZH-159

Establishing Design Stress (σ)

Material properties used in bending moment calculations can be more challenging to quantify due to their inevitable inconsistencies and differing applications. Unlike Section Modulus, which is entirely objective, design stress is determined by taking the maximum stress a material can withstand before failure and applying a chosen level of safety, making it much more subjective. Fortunately, The Aluminum Association gives guidelines for determining the design stress for a given structural component.

The Aluminum Association is a non-profit organization that represents the leading producers of aluminum and aluminum products in the U.S. and abroad. They publish the U.S. standard for aluminum structural design, Specification & Guidelines for Aluminum Structures. Only methods endorsed by The Aluminum Association should be used for structural aluminum design. At CMI, we follow their methodology to establish allowable stress for design and ultimately an allowable bending strength or bending moment.

For typical applications involving sheet piling made from 6061-T6 aluminum, a factor of safety of 1.95 is applied to the material’s maximum rated or ultimate tensile strength, 38,000 psi, to arrive at the design stress value of **19,500 psi**.

$$\frac{\text{Max Stress Value}}{\text{Factor of Safety}} = \text{Design Stress}$$

Equation 2
Design Stress Calculation

$$\sigma = \frac{38,000 \text{ psi}}{1.95} \approx 19,500 \text{ psi}$$

Example 2
Design Stress Calculation for 6061-T6 sheet piling

Establishing Modulus of Elasticity (E)

Modulus of elasticity is a material property that describes a substance’s tendency to deform under an applied load. Like design stress, this design value is published in The Aluminum Association’s Specification & Guidelines for Aluminum Structures. They recommend using an **E** value of **10,000,000 psi** for design with all 6000 series aluminum.

Arriving at a Maximum Allowable Bending Moment

In aluminum’s case, like most homogeneous materials, shape and material characteristics (established above as design stress and section modulus) are used specifically to calculate a sheet pile’s bending strength or bending moment capacity. Since bending will typically be the mode of failure with aluminum sheet piling, this should be the primary design criterion. Using the Euler-Bernoulli beam equation, shown below, we can combine material and shape properties to predict bending capacity, where **M** is the maximum allowable bending moment, **Z** is the section modulus, and **σ** is design stress.

$$M = Z\sigma$$

Equation 3
Euler-Bernoulli Beam Equation

A maximum allowable bending moment of **27,625 (ft-lb/ft)** is calculated for PZH-159

$$M = 17.0 \text{ (in}^3 / \text{ft)} * 19,500 \text{ (psi)} = 331,500 \text{ (in-lb / ft)}$$

$$M = \frac{331,500 \text{ (in-lb / ft)}}{12 \text{ (in / ft)}} = 27,625 \text{ (ft-lb / ft)}$$

Example 3
Maximum allowable bending moment calculation for PZH-159

The maximum allowable bending moment should typically be used to select the appropriate sheet according to the requirements of the wall design.

Checking for Excessive Deflection

Although deflection is not typically a structural constraint for homogeneous materials, and there are no current standard design limits for these type applications, it is commonly checked as a secondary measure to ensure that unwanted or excessive deflection does not occur and the aesthetics of the wall are maintained. Much like in bending strength, the combination of shape and material properties allow the prediction of how the structure will deflect under load. There are many different deflection equations, each depending on conditions specific to the application, but they are all a function of a sheet pile’s stiffness, shown below, where E is the material’s modulus of elasticity, and I is the shape’s moment of inertia.

$$\text{Stiffness} = EI$$

Equation 4
Stiffness Calculation

Laying corrosion concerns to rest

When aluminum is exposed to the atmosphere, a thin, invisible oxide layer forms instantly on its surface. This oxide layer gives aluminum its superior resistance to the damaging effects of corrosion. The United States Army Corps of Engineers states that as a material for sheet piling applications, “Aluminum has excellent corrosion resistance in a wide range of water and soil conditions because of the tough oxide film that forms on its surface. Although aluminum is an active metal in the galvanic series, this film affords excellent protection except in several special cases.”¹

The Aluminum Association adds “Unless exposed to some substance or condition which destroys this protective oxide coating, the metal remains resistant to corrosion. Aluminum is highly resistant to weathering, even in many industrial atmospheres which often corrode other metals. It is also resistant to many acids.”²

If a “special case” is encountered, eliminating areas of concern in the design phase of the project can be much more effective and convenient than waiting for problems to arise in the field.

While 6000 series aluminum is the best metal for use in waterfront construction, there are several design options that may be considered for added protection. If possible, dissimilar metal contact should be avoided to limit galvanic action. If non-aluminum fasteners will be used, stainless steel is preferred, but hot dipped galvanized fasteners are also recommended by The Aluminum Association. To further limit galvanic action, it is also recommended that you isolate dissimilar metals with a non-absorbent insulator like paints or non-porous synthetics. Some less obvious dissimilar metal contact may result from the use of pressure treated wood (CCA, ACQ, etc.), and re-enforced concrete.

Aluminum’s tough oxide layer is generally stable in the 4.5 to 8.5 pH range, making it suitable in the most common marine environments, however checks should be made to ensure that native soils and backfill materials are not extremely acidic (high chloride content, etc.) or basic (High clay or organic content, most concretes, etc.). If economical to do so, it is recommended that areas that require contact with extreme pH levels also be isolated with a resistant, non-absorbent insulator. Due to the typically high pH of most aggregates, isolation is typical when forming a concrete cap. In the unusual event of soils with extreme pH levels, to further reduce the chance of damage due to corrosion, cathodic protection or a sacrificial anode systems may be applied. These tools enhance the corrosion resisting ability of aluminum.

Review

There are several key steps to consider when designing with aluminum sheet piling.

- Ensure that an appropriate alloy is being used in regards to both strength requirements and environment.
- Establish an appropriate design stress.
- Determine the section modulus from the cross section of the selected sheet pile.
- Determine the maximum bending moment to be carried by the selected sheet pile, and ensure that this value is greater than that calculated for your wall design requirements.
- Check for undesirable deflection.
- Ensure that the application and environment are suitable for aluminum and establish any required measures concerning these elements in the design phase.

It is our hope that, with the steps laid out and information presented here, the designer or end user will be able to make a more informed and responsible decision regarding the selection and application of aluminum sheet piling.

1. United States Army Corps of Engineers. EM 1110-2-1614 Design of Seawalls and Bulkheads. Washington DC: USACE, 1995
2. The Aluminum Association. Specifications & Guidelines for Aluminum Structures. 8th ed. Arlington, VA: The Aluminum Association, 2005