

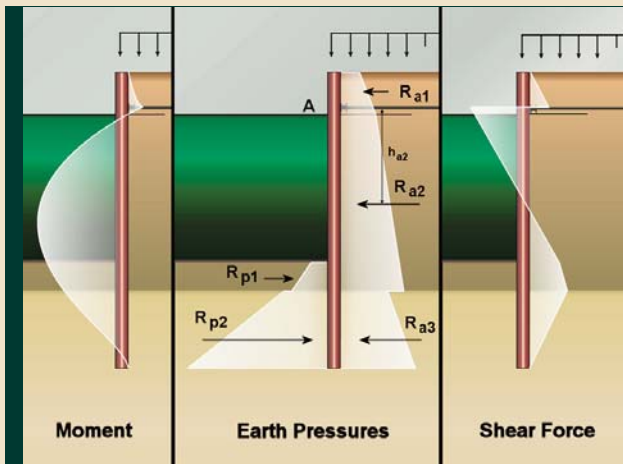
The Material Truth



Steel vs. Synthetics: A Direct Comparison

**The Designer's Guide to Engineering Seawall
and Bulkhead Retaining Structures**

► Design Basics



Pressure Diagram

The initial objective in retaining wall analysis is to obtain the maximum moment (M_{max}) caused by the loads. With steel sheet piles, the allowable stress (σ_{all}) is used with M_{max} to determine the minimum required section modulus.

$$S = \frac{M_{max}}{\sigma_{all}}$$

The allowable stress for a sheet pile material is a critical component of the analysis. But what is it exactly? *Allowable stress* is a design parameter where the stresses developed from loading the structure do not exceed the materials elastic limit.

Elemental to simple beam theory, this has been the method of retaining wall analysis for many years. The process does not directly account for the multi-directional loads that sheet pile shapes undergo, but the homogenous material strength of steel and applied safety factors to the allowable strength allows designers to blanket specify “section modulus” as the sole strength requirement. This process is applicable to steel only, but has been incorrectly substituted by designers for synthetic shapes (vinyl, Fiber Reinforced Polymer (FRP) composites).

Section Modulus (S) is the most misunderstood term in sheet pile design. It is nothing more than a geometric reference for a structural shape where the moment of inertia (I) is oriented about an axis through the centroid, and (c) is the distance from the centroid to the extreme edges of the section.

$$S = \frac{I}{c}$$

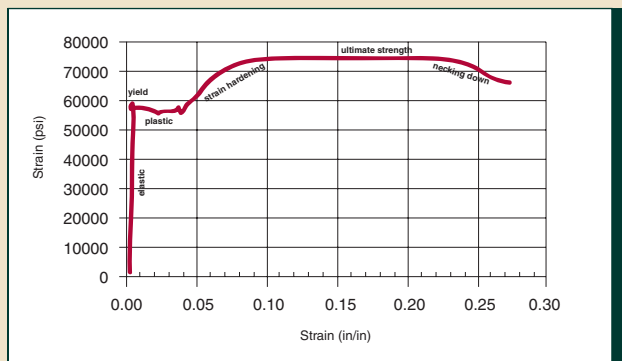
Regardless of material makeup, identical shapes have equivalent section moduli and moments of inertia. In the case of synthetic sheet piles, the design practice of specifying both properties is not so simple. Unlike steel, vinyl and composite FRP are anisotropic and do not have uniform mechanical characteristics in all planes. This reveals synthetics’ inferior material properties while showing steel’s isotropic strength and inherent applied safety factors. Plain and simple, vinyl and FRP are taking the structural capacity out of these engineering terms.

Synthetics do not have homogenous properties; producers are using engineering terminology to define their sections. The information is not false, but it is intended to mislead engineers into thinking they can design synthetic sections just as they would steel. The behavior of the synthetic sheets and the differences between steel profiles needs to be understood to properly design synthetic sheet piles for bulkhead and retaining structures. No matter how they try to present their data, it still comes down to four basic design criteria: **strength, stiffness, drivability and durability.**

► Strength of Materials

Strength

For steel, the yield strength is the point at which the loading stress plastically deforms the material. Once the steel has entered the plastic range it will no longer return to its former shape. For commodity structural steel, the yield strength ranges between 50 and 65 ksi. The graphic below demonstrates the elastic and plastic ranges. Steel exhibits a very linear stress strain relationship up to a well defined yield point. The slope or ratio of tensile stress to tensile strain is the modulus of elasticity (E).



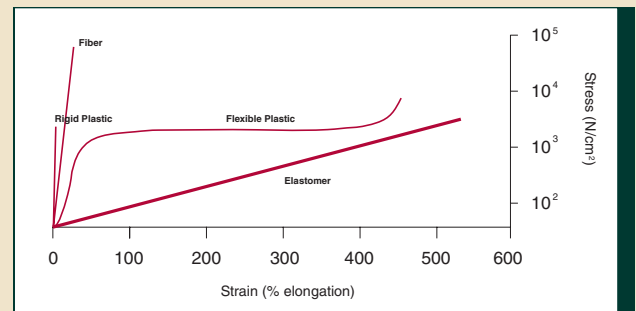
Stress Strain Curve: Steel

The second strength aspect for beam analysis is bending. Bending strength characterizes a beams ability to resist moments. Not to be confused with Flexural stress, which is a phrase used by the synthetics industry and is meaningless for sheet pile design. Lateral loads are expressed in compression and tension to form a couple or bending moment equal in magnitude and opposite in direction. Bending strength is then derived from the following equation:

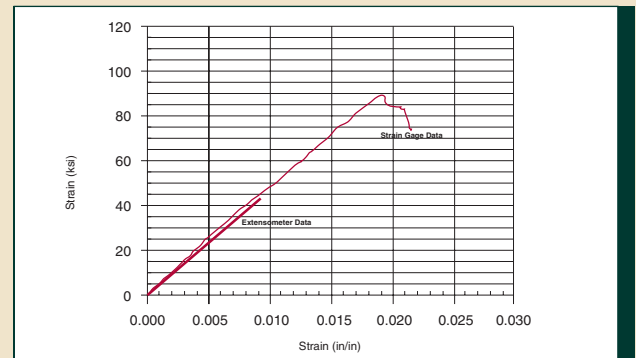
$$S = \frac{\sigma_{all}}{FOS}$$

For synthetics, tensile is the only strength parameter that is clearly defined. Vinyl boasts 6 ksi of tensile capacity while FRP has 10 – 15 ksi in the transverse direction and 60 – 90 ksi in the longitudinal plane.

For anisotropic materials, it is difficult to precisely define true material yield due to the lack of a clear border between the elastic and plastic regions in these materials. The yield point can be defined as the stress point at which the material will no longer return to its original shape. At the yield point for steel, the material has undergone a very small portion of the deformation it will experience before failure. Also, as steel elongates it becomes stronger (strain hardening), which offers additional capacity before it will fail permanently.



Stress Strain: Vinyl



Stress Strain: Composite

The stress strain curve for FRP has no strain hardening phase as steel demonstrates. The elongation range between yield and ultimate is much smaller in plastics, thus leading to **sudden failure without warning**.

► Material Performance

Stiffness

The stiffness of a structure is of principal importance in many engineering applications. Modulus of elasticity is one of the primary properties considered when selecting a material. A high modulus of elasticity is sought when deflections are undesirable.

Modulus of Elasticity

Steel	30,000,000 psi
FRP	6,100,000 psi
Vinyl	380,000 psi

Stiffness is the ability of a material to resist deformation under load. Elastic modulus is not the same as stiffness. Elastic modulus (E) is the ratio of stress over strain for a material. Similar to the issue of section modulus and its relevance being dependent on material strength, the material's elastic modulus validates structural credibility for the geometric property moment of inertia (I). Two identical shapes can claim the same moment of inertia, but have different (E) moduli. This is the case when comparing a steel sheet pile section to a vinyl or FRP section. This relationship can be expressed linearly as:

$$\text{Stiffness} = E * I$$

Deflection is a limiting design factor for sheet pile structures and is **inversely proportional** to the material's modulus of elasticity.

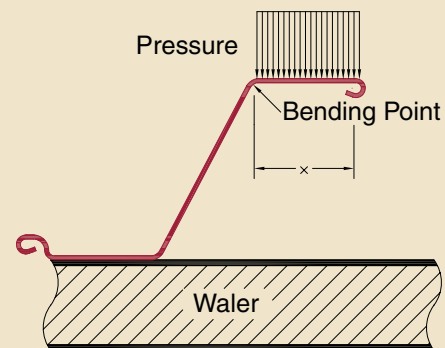
Deflection

Steel	1.00 inches
FRP	4.92 inches
Vinyl	78.95 inches

Previously we discussed how the bending strength of a section is determined by the yield strength and the section modulus.

Using the elastic section modulus to determine the stress in a pile is a one dimensional view of the actual stresses in the structure. Multi-directional loads occur, but are almost always ignored in the design of steel sheet piles because they are less than the primary bending stress.

Sheet piles are structural elements that make up a wall system. Section depth, interlock location, web and flange thickness all have an influence on pile performance. In addition to normal bending behavior, transverse stresses also occur where the flange meets the web. As demonstrated in the graphic below, the shape required for retaining earth and water introduces transverse loads into the wall. Walls in soft soils or water pressure, are even more susceptible to these transverse stresses and often require waler systems.



All piles have a bending point at the web and flange junction which makes them susceptible to failure. The following equation accounts for these combined stresses in steel sections:

$$C = (B^2 + T^2 + B * T) 1/2$$

where: C = Combined Stress
B = Normal Bend Stress
T = Transverse Stress

► Installation Performance

Steel's uniform strength allows designers to ignore transverse stresses for most walls. For synthetic walls though, the transverse strength (~15% of longitudinal strength) of FRP sections make the analysis of the transverse stresses very important. The assumptions made in steel sheet pile design cannot be transferred to synthetics and this critical design step should not be ignored.

Steel sheet piles have the stiffness to offer cantilevered solutions, while vinyl and FRP walls almost always require a tieback or anchorage system to limit deflection. Below you see a typical timber pile and waler configuration designed to support the synthetic wall, relegating the sheet piles to nothing more than lagging panels. In many cases the synthetics are sold as maintenance free walls; however, the wood piles, walers and tiebacks that serve as the true structural elements only have a life span of 8-12 years.



Drivability

Structural consideration for designing a sheet pile wall is primary to the process. Getting the sheet piles into the ground without damage is just as important. A sheet pile will never perform if it cannot penetrate the soils to achieve design depth. Drivability is just as critical to a successful application as are the structural criteria.



Steel sheet pile replacing failed FRP at installation

In non-cohesive granular material, steel sheet piles have the longitudinal stiffness to transfer the oscillating stresses induced by vibratory hammers and suspend the surrounding soil particles as the hammer weight advances the pile downward.

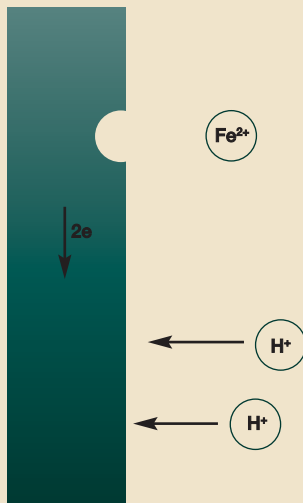
For cohesive environments, impact hammers are better suited to break or shear the skin friction bond between the pile and soil. Steel sheets have the axial capacity to support the hammer weight and effectively transfer energy through the pile for penetration.

Vinyl piles are easily damaged under these driving stresses. FRP sheets have decent impact resistance but are very susceptible to damage from transverse stresses that vibratory hammers induce. Obstructions prohibit the use of either material. That is why most projects require pre-drilling or trenching to place synthetic piles. This is more time consuming and expensive than conventional pile driving. Skyline Steel's Sheeting Solutions is often called upon to value engineer synthetic designs that have either failed during installation or after a short time in service.

► Design Life

Steel Durability

Corrosion is an electrochemical reaction through which an exchange of charged ions between two cells takes place. Most environments provide opportunities for steel to combine chemically with elements to form compounds and return to a more stable state. In general, free or dissolved oxygen is the catalyst and must be present for this reaction to occur. In buried applications, the oxygen is compressed out of the soil; that is why corrosion for the buried portion of the piles is a non-issue.



With more than a century of steel production and a rich construction history, corrosion rates of exposed steel piles in marine and atmospheric conditions have been thoroughly documented. Armed with this knowledge, engineers can effectively predict and design for service life. From sacrificial thickness and coatings, to material grade and moment relocation, engineers have steel durability options that bring long term economical design solutions to seawalls and bulkheads.

Synthetics may not corrode in the same manner as steel, but they do degrade. Synthetics such as vinyl and fiberglass all degrade. These materials have inherent oils called plasticizers. Over time, plasticizers migrate to the material surface and evaporate, otherwise known as **outgassing**. As the oils escape, the product loses elasticity and becomes brittle. Color pigments will fade and or become chalky. These are visible signs that the material is breaking down.

As all seawall applications are exposed to the elements, UV light rapidly accelerates material degradation. The addition of UV inhibitors to the resins theoretically will slow down the process, but as they are consumed, degradation continues. Synthetics are relatively new materials. Regarding research and development, they are considered to be in the infancy stages. The long term effects of marine exposure are still undefined.

Another concern with synthetics in marine walls is **absorption**. When not in use, fiberglass boats are removed from the water for this exact reason. Long term exposure to water or moisture will inevitably lead to intrusion. This intrusion changes the mechanical properties and leads to failure.

Creep is also a major threat to synthetic seawalls. It is a time-dependent deformation that occurs to the material while under an applied load below its yield strength. It most often occurs at elevated temperatures, but some materials are capable of creep at room temperatures. Creep can cause significant deformation and failure if steps are not taken in the design.

► Sheeting Solutions

As we have come to learn, seawall and bulkhead structures are much more complicated than synthetic sheet pile producers would like you to believe. There are a multitude of design pitfalls that can be presented merely by the material considered. It is critical to not only understand the load behavior, but to also understand how the material and sheet pile section will perform in these conditions.

Whether you are designing a new seawall or retrofitting an existing bulkhead, Sheeting Solutions only offers wall systems based on sound engineering principles.

The Sheeting Solutions group within Skyline Steel was developed to market steel sheet pile solutions for light marine bulkhead and retaining wall applications. With an extensive range of domestically produced cold formed sheet pile sections, and a groundbreaking coating technology, Sheeting Solutions has the most innovative steel sheet pile system. By combining the strength of steel with the aesthetics and durability of marine grade cladding, the X-treme Performance System (XPS) is revolutionizing marine structures.

Sheeting Solutions produces the X-treme Performance System at our state of the art, Belpre, OH manufacturing facility. Our sales professionals are strategically located to service key regions for the light marine markets.

To learn more about XPS and Sheeting Solutions, contact one of our sales or engineering professionals today.



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