



## **Product Design Theory and Basic Engineering Properties**

A CMI Technical White Paper

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Physical properties are defined by ASTM testing standards, The Aluminum Association Design Manual, 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. ShoreGuard, C-Loc, TimberGuard, GeoGuard, Dura Dock, Shore-All, and Gator Gates are registered trademarks of Crane Materials International. ArmorWare, Ultra Composite, GatorDocks, and CMI Waterfront Solutions are trademarks of Crane Materials International. United States and International Patent numbers 5,145,287; 5,881,508; 6,000,883; 6,033,155; 6,053,666; D420,154; 4,674,921; 4,690,588; 5,292,208; 6,575,667; 7,059,807; 7,056,066; 7,025,539; 1,245,061; Other patents pending. © 2007 Crane Materials International. All Rights Reserved.

## Product Design Theory and Basic Engineering Properties

CMI is constantly introducing new products as low cost solutions to our customer's needs. Every new and existing product is scrutinized extensively by our engineering personnel to ensure that they will meet and exceed the performance standards our customer's desire.

CMI's detailed engineering design program, in conjunction with extensive analytical, field and experimental performance results, provide peace of mind for our customers in knowing that we have thoroughly evaluated and proven the performance of all of our products.

CMI continues to provide sheet piling design innovations through extensive research and development, and relies on a world-class engineering team to establish material capabilities as well as the interaction of stresses experienced in the finished product. It is of paramount importance that all factors of the products performance are analyzed carefully. And although it is relatively simple to determine the moment capacity of a sheet piling relying solely on coupon tests and simple engineering calculations, this type of analysis can provide misleadingly high results.

Our products are not only designed with a simplified theoretical overall bending strength, but all aspects of cross sectional loading and buckling as well as ancillary stresses and deformations are analyzed and tested by advanced computer modeling and Finite Element Analysis techniques by both internal and third party engineers.

Finally, finished product performance is proven through extensive internal and third party testing of both material coupon cut outs, and full length full product sections.

- *Finite Element Assessment of Two Interlocking PVC Sheet Piling Designs* by The Ohio State University
- *C-Loc Sheet Piling FEA Analysis* by Product Design Center
- *Full Section Deflection Testing of Sheet Piling* by Crane Component Company
- *Evaluation of Deflection of Sheet Piling* by the Ohio Department of Transportation

- *Flexural Modulus Evaluation* by FTI/SEA Consulting
- *Evaluation of ShoreGuard Rigid Vinyl Sheet Piling* by BF Goodrich Company
- *Strength Evaluation of Sheet Piling* by Science Applications International Corporation
- *Deflection Analysis of ShoreGuard Sheet Piling* by Materials International
- *16-year Creep Study of PVC* by Brown University
- *U.S. Army Corp of Engineers, CMB Report 02-008, Results of Vinyl Sheet Pile Materials Investigation for New Orleans District* by Joe G Tom and Judy C. Tom
- *1,000 hour QUV Test (ASTM G53-96)* by the Illinois Department of Transportation, Bureau of Materials and Physical Research
- *Physical Property Retention - 5 Year Weathering Study* by BF Goodrich., Cleveland, OH
- *Evaluation of BF Goodrich Geon Vinyl for Use in Plastic Sheet Piling System* by BF Goodrich Company, Advanced Engineering and Design Laboratory

### Stress, Strain and Modulus

The structural performance of all materials is primarily controlled by two main factors:

Stress ( $\sigma$ ) – Applied force over a given area. Usually given in pounds per square inch (psi), or pascals (Pa)

Strain ( $\epsilon$ ) – The amount of deformation or stretch of a material. Usually given in inch per inch (in/in) or percentage (%)

Stress and strain for isotropic materials are related by Hooke's law:

$$\frac{\sigma}{\epsilon} = E$$

Where E is the modulus of elasticity and usually given in pounds per square inch or pascals.

Therefore E is a number that describes the amount of stress required for a unit elongation, or more simply put the

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stiffness of a material.

The maximum amount of stress or strain a material can withstand before failure are known as:

Ultimate Stress ( $\sigma_{ult}$ )

Ultimate Strain ( $\epsilon_{ult}$ )

$E$ ,  $\sigma_{ult}$ , and  $\epsilon_{ult}$  are material properties only and are not controlled whatsoever by cross sectional or other shape parameters.

## Moment of Inertia

The bending performance of a particular beam is largely controlled by a cross section property known as the second moment of area or more commonly known as the moment of inertia ( $I$ ).

The moment of inertia is based solely on the shape of a cross-section, or area, and not controlled whatsoever by material properties.

Moment of inertia is calculated as follows:

$$I_x = \int_A y^2 dA$$

Where the moment of inertia of area  $A$  is calculated about axis  $x$ .

The units for moment of inertia are most commonly inches to the power of four ( $\text{in}^4$ ), or millimeters to the power of four ( $\text{mm}^4$ )

## Bending Moment

When a component is subjected to beam loading (i.e. the loading is applied perpendicular to the components longitudinal axis), there is an occurrence known as a bending moment induced in the beam. The induced bending moment is a factor of the supporting and loading conditions only and not material properties or beam cross-section, and varies through the length of the beam.

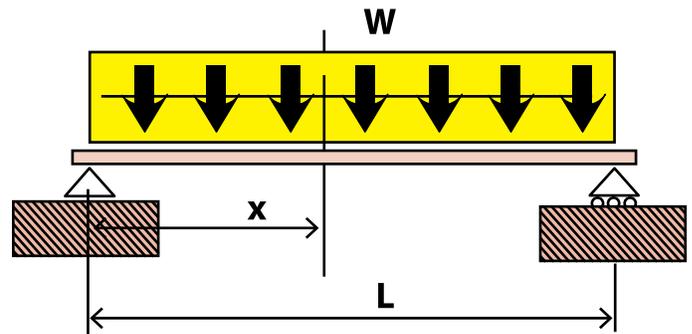


Figure 1

*Simply Supported Beam with Uniformly Distributed Load*

The loading configuration of a sheet piling wall is extremely complicated, therefore for this section we will examine more simplified loading cases for illustration purposes. Please refer to [Fundamentals of Wall Design, a CMI White Paper](#) for more detailed information on sheet piling loading configurations.

For a simply supported beam with a uniformly distributed load (Figure 1), the maximum bending moment occurs at mid

$$M_{\max} = \frac{wL^2}{8}$$

span and can be calculated as follows.

Where  $M_{\max}$  is the maximum moment,  $w$  is the distributed load, and  $L$  is the span. Bending moment can be visualized as a force applied at a distance or moment arm and is usually reported in foot pounds (ft-lbs) or newton meters (N-m).

## Bending Stress

The bending stresses induced in the cross section of the beam are primarily tensile stresses in the bottom section reaching a maximum at the bottom edge, and compressive stresses in the top section reaching a maximum at the top edge. The bending stresses can be calculated as follows:

$$\sigma = \frac{My}{I}$$

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Where  $y$  is the distance of the stress element from the neutral axis of the cross section.

To calculate the maximum bending stress,  $y$  is replaced by the distance from the neutral axis to the outside edge of the cross section ( $c$ ).

$$\sigma_{\max} = \frac{Mc}{I}$$

For a symmetric cross section,  $c$  can be assumed to be half of the cross section depth.

In order to simplify calculation the previous equation can be replaced by:

$$\sigma_{\max} = \frac{M}{Z}$$

Where  $Z$  is known as the Section modulus, and, for a

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

symmetric cross section:

Section modulus is usually reported in inches cubed ( $\text{in}^3$ ) or millimeters cubed ( $\text{mm}^3$ ), and is a shape property only.

### Deflection

The deflection of a beam is principally a function of the moment of inertia of the beam cross section, and the modulus of elasticity of the beam material. Generally speaking, the higher the moment of inertia and modulus of elasticity of a particular beam, the lower the deflection and therefore stiffer the beam will be in bending.

For the situation noted in Figure 1 in the bending moment section, the maximum deflection will occur at the center of the span and can be calculated as follows:

$$\Delta_{\max} = \frac{5wL^4}{384EI}$$

Where  $\Delta_{\max}$  is the maximum deflection usually reported in inches (in) or millimeters (mm).