



INTERIM REPORT

General Design Guide: PVC Sheet Pile

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PREFACE

This interim report documents the progress of our effort on developing the design guidance document for PVC sheet piling to be used in the Goose Bayou Project, located in the New Orleans District, Louisiana. Use of newer materials in construction requires caution, especially when lives and properties are at risk. Numerous concerns have been raised and addressed during writing of this document. We encourage the readers not to hesitate to raise those concerns and issues so that in the final report we can address them as completely as we can to make that a comprehensive document. Mr. Walter O. Baummy, CEMVN-ED Chief Engineer, New Orleans District sponsored this work.

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General Design Guide

PVC Sheet Pile (Tidal Protection)

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PVC Sheet Pile

1. INTRODUCTION

PVC sheet pile is an economical alternative for constructing minimum height floodwalls, erosion protection, seepage cut-off wall, temporary coffer dam, stream bank restoration and floodplain management.

This report provides practical design guidance developed from the ERDC/CRREL Letter Report (Aug 03) “A Study of the Long-Term Applications of Vinyl Sheet Piles” for the use of PVC sheet pile, and provides a designer guidance that takes into consideration the material characteristics, loading characteristics, and exposure characteristics of this lightweight pile.

In addition, this report addresses concerns raised in the Corps of Engineers, Engineering and Construction Bulletin, Vinyl Sheet Piling, issued 10 Oct 02 (ECB No.2002-31). These issues are categorized at three levels: COMPONENTS, SYSTEMS and MAINTENANCE. . The issues at the component level are the engineering performance and the long-term environmental effects on the engineering properties of the PVC. At the system level, the concern is that PVC is more flexible than the traditional materials (steel and concrete) for which traditional design techniques are based on stresses, not deflections. As with many other construction materials PVC can be damaged from large debris impact during flood, abrasion, extreme/excessive heat and vandalism, and therefore will require special design approaches to neutralize or minimize the effects of those hazards and a rapid repairing operation to maintain the integrity.

This report is to serve as a supplement to the Corps of Engineers collection of Engineering Design Manuals for protections systems and their application for utilizing PVC sheet pile for installation of a tidal protection wall. The design criteria used in this report are specific to the Goose Bayou Project located in the New Orleans District and based on the hydraulic load, wave load, wind loads and the environmental and site conditions for Goose Bayou in Jefferson Parish, New Orleans, Louisiana. The design recommendations may be applied to other sites with similar design characteristics, and environmental and geotechnical conditions.

The report is organized in seven sections. The next section, Section 2, gives a background on PVC as a material, which has also been explained in detail and available in ERDC/CRREL **2003 Report LR-03-19**.

http://www.crrel.usace.army.mil/techpub/CRREL_Reports/reports/LR-03-19.pdf

Section 3 deals with the expected performance of the PVC material based on the ASTM cell classification. Section 4 gives the design approach, Section 5 deals with the design procedures and some examples. Section 6 briefly outlines the installation and maintenance, and Section 7 gives the general remarks. The design related issues in sections 4 through 6 have been dealt with in a general way. The in-depth analysis of the issues will be given in the forthcoming final report.

2. BACKGROUND

To increase the level of flood protections of existing levees it is usually necessary to increase the height of the levee, which translates to significant cost increase for purchasing real estate to broaden the levee footprint. Simply elevating the height of the levee may be complicated by low bearing capacity of the underlying material being unable to support the surcharge. An alternative is to build a short cantilever floodwall on top of the levee, conventionally done using steel sheet piles.

Floodwalls are designed to provide additional protection from storm waves superimposed on tidal fluctuation of the mean water level, which is at or below the project height of the levee system. The cantilever pile sections are on the order of 3 to 6 ft, which is supported by the soil surrounding the buried section. The use of steel sheet piles results in a very conservative design requiring heavy equipment to transport and install the wall, which translates to a higher construction cost. PVC sheet piles are a viable alternative to steel with multiple benefits but with some limitations. The lower manufacturing cost combined with the lighter weight of the sections for easier transportation and handling and reduced size of equipment required for installation translate into a net reduction in the construction cost. A secondary benefit of PVC is its non-corrosive nature, however, unlike steel, PVC's engineering properties can be affected by UV rays therefore requiring special emphasis on the UV protection additives when the chemicals are compounded and the sheet pile profiles are fabricated.

Because PVC is not a direct substitute for steel the designs are sometimes not as conservative; but by following sound engineering practices PVC floodwalls can be just as effective as a steel system. Figure 1 shows an example of a floodwall built using PVC sheet pile in the town of Westwego, located across the river from New Orleans. The wall is roughly 250 ft long and was built using 20 ft long sheet piles, using the buried 16ft to support the 4-ft high cantilevered flood wall. Section characteristics of the PVC sheets used for the Westwego flood wall are; web thickness of 0.40 in, section modulus of 19 in³/ft, moment of inertia of 76 in⁴/ft, and nominal section depth of 8 in. The structure has withstood four hurricanes since its completion: George, Elly, Isidore and Ivan. The only damage to the wall was done by a mower that damaged the tops of the piles as the sheet pile wall transitioned into the full levee embankment section.

The Goose Bayou project is a tidal protection project; like other floodwall projects the mean water level is below the top of the levee. The floodwall is being added to protect the area from water level variation due to tide, wind stacking of the water and waves. Although the system is not intended for hurricane protection, the system would be able to survive one.



Figure 1 PVC sheet pile floodwall installed (Jan 98) in the town of Westwego, Jefferson Parish, LA

The design has to consider the life-cycle cost and the aesthetics of the floodwall. Unlike conventional steel sheet piles, PVC is flexible, which as mentioned before, can control the design. The object of this report is to provide the designer an appreciation and limitations of PVC sheet piles to allow the designer to use engineering judgment. As stated, the recommendations are for the Goose Bayou in Jefferson Parish, New Orleans or sites with similar environmental and geotechnical design conditions. The report is a supplement to the existing EM 1110-2-2504, March '94 - Design of Sheet Pile Walls, providing design guidance for preparation of plans and specifications for use of the applications that policy allows. This documents addresses the concerns raised in Corps Engineering and Construction Bulletin 2002-31, dated 10 Oct 2002 Subject: Vinyl Sheet Piling, Applicability: Guidance.

2.1 ENGINEERING AND CONSTRUCTION BULLETIN No. 2002-31 – ENGINEERING ISSUES.

The ECB Bulletin No.2002-31 refers to the EM 1110-2-2504, 31 March 94, Design of Sheet Pile Walls, which states that in case of the PVC or any such nontraditional materials the properties must be obtained from the manufacturer and must be carefully evaluated by the designer for each application. The ECB Bulletin 2002-31 specifically asks the designer to consider a number of engineering issues. We have considered those issues which are commented on below.

Integrity of vinyl sheet pile: The ECB No.2002-31 suggests that because of the concerns about the integrity of PVC sheet pile, PVC sheet piling should not be used when life safety and widespread property damage are at stake in the event of failure, for example in providing the main line of flood or hurricane protection. When the stresses exceed their limits in the material of a structure, the material, and therefore the structure, fails. It seems that the ECB 2002-31 alludes here to an incomplete data or understanding of the limit stresses of the PVC materials or the magnitudes of stresses that would be induced in the sheet piling structure under some extreme loading. PVC is a well studied engineering material, and its limit stresses are well known. Therefore new designs based on sound structural analysis with a conservative margin of safety can be developed for the PVC sheet piles, and as a confidence building exercise, these sheet piles have been used initially in situations where the risk to life safety is extremely low and widespread property damage are not envisioned.

PVC is a well researched and well understood material and as with any structural material, PVC is safe when used within allowable stress and strain limitations

Durability: The ECB No.2002-31 also suggests that manufacturers claiming 50-years life for their PVC sheet pile should corroborate the accuracy of such claims with independent testing and evaluation and provide a specification for PVC sheet piling that meets USACE requirements. Durability of a material needs to be understood in terms of the changes in behavior or properties over a period of time. For PVC there are two causes which can affect its behavior over time: *Physical Aging:* Industrial manufacture of PVC involves processing at high temperature and then cooling below T_g (glass transition temperature). Quick cooling does not allow complete molecular relaxation, leading to a nonequilibrium state. As a result the relaxation process continues for a long time. Both time and temperature influence this process. Information on physical aging collected by Rabinovitch and Summers [1992] shows that the aging results in an increase of T_g , heat deflection temperature, modulus of elasticity, tensile strength, and brittleness (impact strength reduction). The extent of these changes depends on aging time and temperature. Therefore, except for the impact strength reduction the physical aging process must not be of great concern in using PVC for sheet piling. The other cause is *Weathering:* Weathering involves exposure to ultraviolet (UV) light, rain, snow, and temperature cycling, which may lead to chemical aging. The chemical aging primarily involves light-initiated free radical formation, loss of hydrogen chloride, autoxidation, bleaching, and possibly crosslinking. This leads to discoloration, surface erosion, and embrittlement. This type of aging occurs only on the exposed surface and is limited to the depth of no more than $150\mu\text{m}$ (0.006 in) (Rabinovitch, Summers and Northcott, 1993). The UV degradation is usually controlled by lowering of UV light available in the plastic. This is done by adding UV absorbing or scattering pigments such as carbon black or titanium dioxide. This prevents the UV light from reaching very far into the plastic (Gerlock and Bauer, 1988). The impact strength reduction issue has been discussed in detail by Dutta [2003] in his report ERDC/CRREL 2003 Report LR-03-19. This report shows how to account for the impact strength reduction over the age of the PVC sheet pile installation.

The longevity and durability of PVC has been extensively tested. Furthermore, PVC sheet piling in service for over 10 years has been inspected to be in good condition by CRREL. As long as known and well specified materials are used, as described in this report, the longevity of PVC sheet piling can be substantiated.

Damage from Impact, Excessive Heat, and Vandalism: These issues arise out of concerns about accidents, sabotage, and vandalism. These are maintenance issues which can not be

designed for and are specific to the PVC sheet pilings due to the lower hardness and strength compared to steel to which the users are familiar. These special maintenance issues will be addressed later in this design guidance document.

Material Standards, Serviceability, Interlock Strengths, Fatigue, Effects of Ambient Temperature, and Geometrical Shapes: These are important design issues which are being dealt with in this design guidance document. The selection of PVC material using the ASTM cell classification (ASTM D4216-03) standard is being recommended. The serviceability requirement in terms of thickness of the PVC profile is a basic design issue. Profiles of PVC sheet piles in various thicknesses are available commercially. It is a reasonably simple task to calculate the moment strength requirements from the applied load conditions with the appropriate factor of safety, and then select the vinyl sheet piling profile that matches the predicted site conditions. These details are being dealt with in detail later in this document (Section 4). The issues of interlock strength have recently been investigated (Vaidya et al 2005).

In most cases when the sheet piling is in bending, the interlocks would be subjected to compression loading which makes them less likely to disengage. The fact that the interlocks have not failed in general in millions of feet of PVC sheet piles being driven each year shows that there are no significant problems with existing designs. Similarly, fatigue is also not a significant issue, as after driving, the sheet piles usually are subjected only to sustained loads. The only other vibrational loads could be wind loads or in submerged structures the wave loads, both are insignificant in causing fatigue.

High temperature in service can cause some reduction in elastic modulus, which can be incorporated in the design factors. Low temperature usually enhances the properties (both elastic modulus and strengths increase). Only the impact strength decreases slightly. Thus driving sheets in cold weather with an impact hammer could present problems, but as of yet has not. Field reports from the New England Division have not reported any such problems (Vaghar 2005). Inspections of 10 years old PVC sheet piles in New Jersey areas where they have undergone many freeze thaw cycles have revealed no problems (Dutta and Vaidya, 2003).

There are current industry standard, comprehensive material standards available for extruded vinyl, that can and should be applied to sheet piling. When these standards are used as prescribed by this guidance document, PVC sheet piling has been shown to resist any measurable problems with fatigue or ambient temperature. The geometric design of the products available currently have been shown to be sufficient to resist interlock failure and site serviceability conditions.

Design Allowable Stresses: It is true that there are currently no national consensus industry standards for the level of allowable stresses that that should be used for PVC sheet piling. An allowable creep stress must also be specified where a sustained load is expected. There are however, widely accepted ultimate stress levels for PVC of 6,500 psi and higher, and varying creep stress limitations. After an extensive study of materials standards and testing as well as inspection of installed product it can be reasonably assumed that an allowable design stress of 3,200 psi is sufficient for vinyl sheet piling when used as prescribed by this guidance document.

As will be clear later in this document, it is not always the stress, but the allowable deflection that will be the critical factor in the design of the PVC sheet pile for cantilever applications. In the absence of any national standard on this it will depend on the designer to specify what maximum

deflection will be allowed in the design. Because deflection is a serviceability limit rather than a failure limit for PVC sheet piling it is critical that the designer specify limitations based on the specifics of their particular project.

3. PVC – STRUCTURAL MATERIAL

The technology that has brought us vinyl siding for homes, plastic automotive parts such as bumpers and dashboards, and durable home appliances, is now being utilized to produce a sheet piling for marine retaining walls, sea walls or bulkheads. Polyvinyl chloride (PVC), typically referred to vinyl sheet piling is a relatively new type of sheet piling, which is manufactured by a continuous extrusion process. Rather than using virgin PVC the manufacturers of PVC sheet piles normally use reworked post-industrial non-consumer PVC. Reground non-consumer PVC is mixed with additives to produce desired color and gloss performance. ERDC/CRREL 2003 Report LR-03-19 gives a general outline of the PVC manufacturing process.

In the manufacturing process the melted resin is pushed through a die having the desired geometry of the sheet pile profile. Different manufacturers produce different geometries of the profile. The molten PVC material exits the die as a formed piece, which then goes through a series of ‘sizers’ that bring the product into proper tolerance as it goes through cooling baths to set the final shape. The exited product from the bath is cut into specified lengths.

The extrusion process can be subdivided into two subcategories. Mono-extrusion, is where a single material is used in the process to fabricate the entire product. Mono-extrusion is normally done with all “virgin” material, but in some rare cases non-consumer reprocessed PVC is used. In a co-extrusion process, a capstock, which is the outer layer exposed to weathering, is usually a “virgin” PVC, and the interior, or substrate, of the product is made up of reworked post-industrial PVC. This outer PVC layer is extruded along with the substrate in a contiguous extrusion process. Because the process is seamless, and is accomplished at high temperatures and pressures in a sealed environment where no moisture or air can be entrapped, it is virtually impossible to separate the layers of a co-extruded product.

No ASTM standards are currently available for PVC sheet piles; however, the standards for rigid PVC exterior profiles for fencing and railing are available as ASTM F964-02. This is the closest standard to the PVC sheet piles. This ASTM standard recommends a capstock thickness should be no less than 0.015 in at any point.

The substrate raw materials used in designing or compounding of the resins ultimately controls the performance of the finished product. The cell classification of the exterior material must be established as minimum by periodic testing of the batches of the final sheet pile products. The guarantee by the manufacturers that when exposed to the weather the product will exceed a minimum threshold for the 50-year design-life must be supported by mutually agreeable tests. Unfortunately, due to the inconsistent nature of the UV performance of non-consumer reworked PVC, all exposed surfaces of the sheet piling must comprise virgin materials only. Although batch UV testing of reworked non-consumer PVC material would be valuable, test specimens would need to be taken and tested on a continuous basis because of the changing input materials. Furthermore, UV testing to the level of this guidance document takes years to perform, the results of the tests would not be available nor useful until several years after than specific part was produced.

The long-term performance of the PVC sheet pile is very much dependent on its chemical compounding. Although such compounding and fabrication are critical to the long-term performance of a PVC sheet pile wall, as discussed above, manufacturing standards have not yet been developed by the industry. Therefore, the designer must have sufficient background of this material to use engineering judgment to develop the contract specifications that will meet the functional requirements of the project.

3.1 PVC MATERIALS SPECIFICATIONS

Not all PVCs are designed for the same end properties, in fact, even different “premium” vinyls are intended for different applications and therefore have different performance trade offs. The most reliable method of specifically qualifying a PVC (vinyl) material widely adopted by the plastics industry consists of two steps: (1) **Cell Classification**, and (2) **Certificate of Analysis**.

Cell Classification: Cell Classification specifies the performance characteristics of a vinyl by using an ASTM cell classification (ASTM D4216-03) standard. The Cell classifications are a series of numbers that specify specific short and long-term performance properties of the PVC material. It is universal practice to match a specific cell classification to the properties expected in the application and include that specific cell class in the material specification. The PVC cell classification is described in Table 1.

Table 1. Cell classification from ASTM D4216-03

Designation Order No.	Property and Unit	Cell Limits								
		0	1	2	3	4	5	6	7	
1	Kind of resin in compound	Unspecified	poly(vinyl chloride) (PVC)	chlorinated poly(vinyl chloride) (CPVC)	vinyl chloride copolymer	vinyl chloride blend				
2	Impact resistance, J/m of notch [ft · lbf/in. of notch]	Unspecified	>34.7 [>0.65]	>53.4 [>1.0]	>107 [>2.0]	>267 [>5.0]				
3	Impact resistance, drop dart, Procedure A, Test Method D 4228, J/m [in.-lb/mil]	Unspecified	>4450 [>1.0]	>6675 [>1.5]	>8900 [>2.0]	>13 350 [>3.0]				
4	Impact resistance, drop dart, Procedure B, Test Method D 4228, J/m [in.-lb/mil]	Unspecified	>4450 [>1.0]	>6675 [>1.5]	>8900 [>2.0]	>13 350 [>3.0]				
5	Tensile strength, MPa [psi]	Unspecified	>34 [>5000]	>37.7 [>5500]	>41.4 [>6000]	>44.9 [>6500]	>48.3 [>7000]			
6	Modulus of elasticity in tension, MPa [psi]	Unspecified	>2000 [>290 000]	>2400 [>348 000]	>2600 [>377 000]	>2800 [>406 000]				
7	Deflection temperature under load, 1.82 MPa [264 psi] °C [°F]	Unspecified	>80 [>140]	>85 [>149]	>70 [>158]	>75 [>167]	>80 [>176]	>85 [>185]		
8	Coefficient of linear expansion, cm/cm°C [in/in/°F]	Unspecified	<4 × 10 ⁻⁵ [<2.2 × 10 ⁻⁵]	<8 × 10 ⁻⁵ [<3.3 × 10 ⁻⁵]	<8 × 10 ⁻⁵ [<4.4 × 10 ⁻⁵]	<10 × 10 ⁻⁵ [<5.5 × 10 ⁻⁵]				

The properties given in this Table 1 and the tests defined are expected to provide identification of the performance of the compounds selected. They are not necessarily suitable for direct application in design because of differences in shape of part, size, loading etc.

[Explanation of cell classification: The Cell Classification of PVC consists of 8 digits arranged in a scheme given in Figure 2. The position of each number denotes the property given in the second column. For example the 5th position indicated the Tensile Strength. The value of the number itself gives the column number where the limit values of the properties are indicated with their units. For example, number 4 in the fifth position indicates the PVC of this cell classification must have a tensile strength greater than 44.9 MPa or 6,500 psi. Figure 3 gives the example of a cell classification number with complete explanation of the meanings of each number following the details given in Table 1. Some manufacturers use 4 extra digits after the first 8 digits to specify the UV protection details]

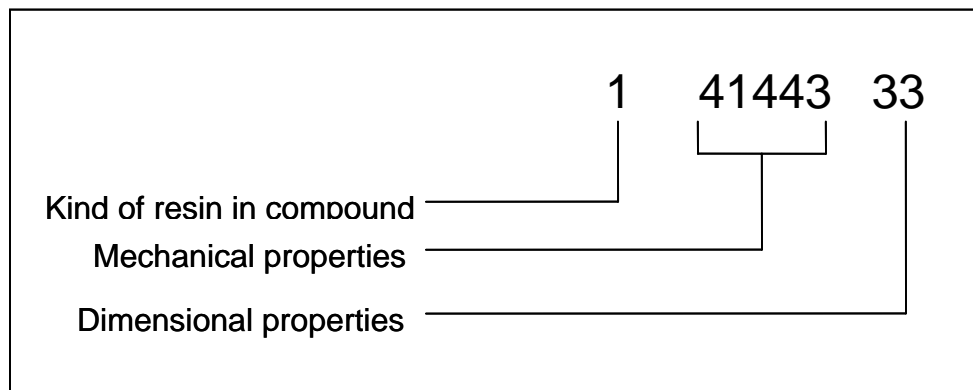


Figure 2 ASTM D 4216-03 Cell Classification numbering scheme

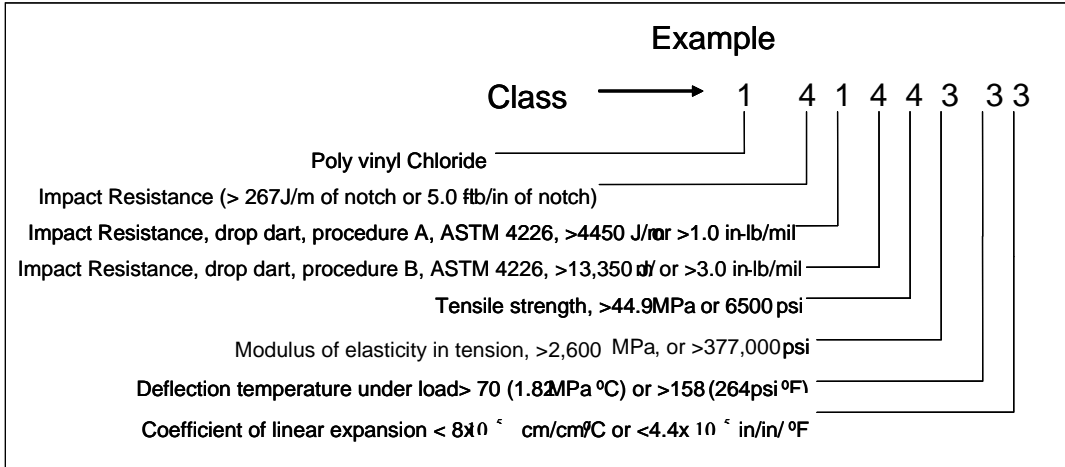


Figure 3 Example of the Classification numbering scheme

The PVC sheet piling designer must have the manufacturer provide the cell classification of the PVC substrate and the PVC capstock material, if any. The manufacturer also should provide enough historical data that the cell classification will not experience any adverse effects to the engineering properties when subject to UV or cold temperatures. The minimum property requirements over the range of temperature from -20 C to 60 C are given in Table 2

Table 2. Required strength properties under cell classification from ASTM D4216-03

Properties	Values
Impact Resistance	
(1)Notch Testing	>5 ft lb/in
(2)Drop dart ASTM 4226 Proc A	>1 in lb/mil
(3)Drop dart ASTM 4226 Proc B	>3 in lb/mil
Tensile Strength	>6500 psi
Modulus of elasticity	>377,000 psi
Deflection Temperature under [264 psi]	>158 °F
Coeff.of linear expansion	<4.4x10 ⁻⁵ in/in/°F

Certificate of Analysis: To qualify the PVC material for the required cell class, it is required that a certificate of analysis be provided by the manufacturer from an ISO certified source. It is critical that the material purchased by the manufacturer meets or exceeds the performance qualifications prescribed by the cell classification. When purchasing a specific virgin PVC compound that specific compound should have been well tested and certified. Once that specific compound has been extensively tested and qualified, an ISO certified PVC compounder has the ability to reproduce the exact same virgin PVC compound on a consistent basis. The industry standard procedure is to then have the ISO certified source (compounder) provide a certificate of

analyses to the manufacturer certifying that all of the material does in fact consistently meet the specified cell classification.

The certificate of analysis ensures that the specific material has been extensively tested and will meet or exceed all of the criteria listed in the cell classification. This is the only way to ensure that the material definitively and consistently meets the requirements set forth by the cell classification.

UV Protection: As mentioned before, the ultra violet (UV) rays have three deleterious effects on PVC: (1) Discoloration, (2) Change of surface texture, and (3) Degradation of impact strength or embrittlement. When fabricating plastic products for exterior use, it is imperative that the material be protected from ultraviolet rays. Gerlock and Bauer (1988) stated in their report that the photolytic instability and degradation of plastic have a direct analog in the corrosion of metals and the full and successful outdoor use of engineered plastics undoubtedly depends on a clear understanding of the chemical changes induced by weathering and their relationship to physical properties. To avoid product deterioration in outdoor use, a UV protection additive is incorporated into the PVC resin during the compounding process. However, despite additives, intense UV radiation can always induce some discoloration. This is evident in a commercial PVC sheet piling material, which did contain UV inhibiting additive, but showed significant discoloration when exposed to very severe UV radiation (five times the intensity encountered on a clear sunny day in a place like Arizona, refer to Figures 17, 18, 19 and 38 of the CRREL/ERDC 2003 Report LR-03-19).

For safety and reliability of operation it is of paramount importance that the Corps of Engineers designs structures with materials that will have minimum assured specific properties over the expected service life of the structure. The minimum assured specific property here relates to the UV protection of the surface layers that is offered by the 'virgin' PVC as defined by the ASTM specification number and identification of the cell classification selected, for example, D 4216, Class 1-32021-22 (Refer ASTM standard 4216-03 Section 5 Ordering Information). Such virgin PVC material will have compound stabilized adequately against changes in color, physical properties, and appearance due to weathering (see Section 8.4 Weatherability of ASTM 4216-03 and the related ASTM specifications D3679, D4477, D4726, and F964). The addition of UV stabilizers such as titanium dioxide during the extrusion process is insufficient to provide stability. The PVC material must be compounded with the stabilizers to be a fully UV stable product.

Manufacturers of new PVC compounds (compounders) are required to demonstrate minimal color, physical property, and appearance change by performing tests in accordance with Section 11.8 of the ASTM D4216-03 specification standard. The Section 11.8 of ASTM D4216-03 specification requires testing of the new compounds for at least two years in at least three widely different climatic areas: a dry hot climate (such as Phoenix, AZ), a hot and humid climate (such as Miami, FL), and a temperate northern climate (such as Ohio, New Jersey).

The Corps of Engineers 2003 research study ERDC/CRREL LR 03-19 Table 2 (Refer : http://www.crrel.usace.army.mil/techpub/CRREL_Reports/reports/LR-03-19.pdf) reports that then existing all three major manufacturers of PVC sheet piles were using 'post-industrial' PVC as the raw material. 'Post-industrial' means previously used in industries or manufactured and then reworked. The reworked material is then re-melted and re-formed into sheet pile shapes by extrusion process. (Refer to Table 2 Answers to question no. 3 of the above report). Such reprocessing may entail contamination with undesirable constituents without suitable and

adequate quality control. Also, in the above referred study, the manufacturers reported adding ‘pigments’, ‘cross-linked acrylic deglossing agent’, or ‘small amounts of colored virgin resin’ to the melt-mix. It is clear that the process involves changing of the original PVC compound with addition of new agents and there are probabilities of contamination. Thus the process may compromise the original quality and properties of the virgin (original) PVC material ensured by the specifications of ASTM D4216-03.

Once the melt mix has been compromised by adding new ingredients, to ensure conformance to the specifications of ASTM D4216-03 of the newly extruded PVC, manufacturers are required to follow the specified weathering tests under the section 11.8 of this standard. If those weathering tests are not performed the UV resistance quality of the surfaces of these new PVC would be open to questions. However, when the surface is recapped with the virgin PVC material that conforms to the specifications of ASTM D4216-03 to a sufficient depth (minimum 0.015 in) the original UV protection would be ensured.

With the use of virgin PVC materials that are certified by an ISO certified source to meet the cell classification requirements called out by this guidance document, vinyl sheet piling has been shown to have adequate UV stability.

Heat and Fire Resistance: PVC by nature will rapidly degrade with high/excessive temperature and may burn with onset of a large fire.

The heat effect must be first taken into account in the design deflection calculation by taking the corrected values of the elastic modulus. Based on a study by Polymer Diagnostics, Inc. (Refer to Figure 8 of Dutta and Vaidya, 2003), it is estimated that within the temperature range of -40°C and 60°C (-40°F and 140°F) the modulus of the commercial PVC for sheet piles decreases at a rate of 363 psi /°C (202 psi/°F). Therefore, suitable allowance must be made in selecting the value of elastic modulus while calculating the deflection of the PVC sheet piles to be installed in locations where daytime summer temperatures are likely to be very high.

The fire issue was also addressed by Dutta and Vaidya (2003) in Section 2 of the ERDC/CRREL LR -03-19. When a flame or heat source is applied vinyl electrical products they typically burn at above 600°F, but they usually self extinguish when the heat source is removed (Vinyl by Design, 2003). Precautions must be taken in the design installations of the PVC sheet wall where grass or other dry vegetation may grow adjacent to the wall, and can catch fire. The vinyl sheet piling will not be a “fuel” to a fire but nonetheless precautions should be taken in order to minimize damage to the sheet piling. One precaution could consist of a “buffer zone” system. A space of 4 ft or more on either side of the sheet piling wall to be maintained free of grass or any other vegetation, by using a layer of gravel or similar inert material. Figure 4 shows a typical “buffer zone” design section located on both sides of the PVC sheet pile wall.

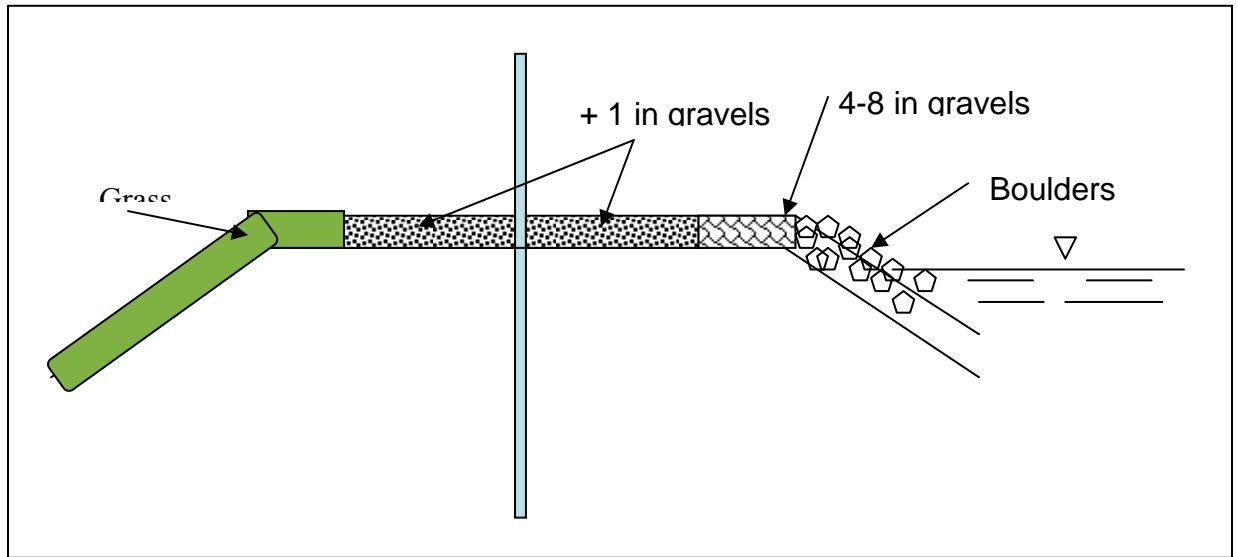


Figure 4 Basic design for fire protection

3.2 MATERIAL PROPERTIES

The manufacturer must provide the material properties data, enumerated below, certified by an independent ISO (International Standards Organization) certified material source.

3.2.1 Physical Properties

Physical properties data to be supplied by manufacturer must include:

- (a) Density or specific gravity, density of PVC is in the range of 0.046 lbs/in³ to 0.056 lbs/in³ which is approximately 5 to 6 times lower than steel.
- (b) Water absorption, 24 hr (%), PVC may typically absorb 0.04 % to 0.4 % moisture depending on the composition and coating.

3.2.2 Mechanical Properties

3.2.2.1 Tensile Properties: The tensile properties of the PVC sheet pile materials must be determined according to the latest ASTM-D638 procedure.

Tensile Strength The acceptable PVC sheet piling material must not have a yield strength less than 6,500 psi (44.9 MPa) to conform to the ASTM D4216-03 classification.

Percent Elongation at Yield, Manufacturer must give this data that will be available from the above tensile test as per ASTM-D638.

Modulus of Elasticity Defined as the ratio of stress (nominal) to corresponding strain below the proportional limit. The acceptable PVC sheet piling material must not have a

linear modulus of elasticity less than 377,000 psi (2.6 GPa), which again must conform to the ASTM D4216-03 classification.

3.2.2.2 Impact Strength The Impact Resistance of the PVC sheet piling material must meet the ASTM D4216-03 Cell Classification designation order 2, 3, and 4 at room temperature.

3.2.3. Thermal Properties:

Thermal properties are needed primarily to assess the dimensional stability. Again the last two cell classification designation order of the ASTM 4216-03 should provide these data.

3.2.4. Chemical Resistance

PVC offers superior performance in corrosive and marine environments. However, if a PVC flood wall is exposed to concentrated hazardous/dangerous chemicals or materials in landfills or hazardous waste sites that would attack the PVC, the chemical resistance of the material against that chemical must be taken into consideration.

Additional technical information on PVC materials, processes, and applications is available from the Vinyl Institute on the web at www.vinylinstitute.com/

3.3 SECTION PROPERTIES

The commercially available rigid PVC sheet piles have various profiles and interlocking arrangements. The profiles and thickness give them the rigidity needed for driving and withstanding service loads. The most common profile configuration is a Z-sheet. The individual sheets have interlocking male and female edges, which interlock with the adjacent piles. There are also transition pieces such as corners and intersections available, which are designed to interface properly with one another.

As mentioned before, compared to steel, PVC is ductile and may not rupture in bending or compression tests. However, it ruptures (separates) in tensile tests. It usually starts yielding, i.e. attaining the non recoverable strain around 6,300 psi (43 MPa). For a ready reference Table 3 compares the properties of PVC and steel. Figure 5 gives a schematic comparison of the stress-strain behavior of these two materials. Note that steel is 80 times stiffer than PVC and the tensile strength of steel is 10 times that of PVC. Classical analysis of sheet pile walls assume that steel is used and the design is stress limited. PVC is very flexible and designs can sometimes be limited by deflection. However deflection still remains a serviceability limit only. Before using designing software, the assumptions used in developing the software need to be checked to ensure the deflection criteria is not ignored. Furthermore, accurate deflection calculations can be complicated beyond the scope of some software. Due to soil relaxation, more simplified deflection models can dramatically overstate deflections and cause overly conservative designs. It is important to ensure that the calculation method you are using is taking into account soil effects such as those modeled by Rowe's reduction method.

It is also important in sheet piling design to consider any potential creep failure. Creep failure is the deformation or plastic flow of the PVC when subjected to any sustained load over time. It is important to keep the sustained stress levels below the level that induces creep failure. Creep deformation will be negligible if the sustained stress does not to exceed 3200 psi.

Table 3 Comparison of the mechanical properties of steel and PVC

Properties	Steel	Rigid PVC (ASTM method)
Tensile strength at break (psi)	$58-80 \times 10^3$	5,900-7,500 (D638)
Elongation at break (%)	21	40-80 (D638)
Tensile yield strength (psi)	36×10^3	5,900-6,500 (D638)
Compressive strength (psi)		8,000-13,000 (D695)
Flexural strength (psi)		10,000-13,000 (D790)
Tensile modulus (psi)	30×10^6	$350-600 \times 10^3$ (D638)
Flexural modulus (psi)		$300-300 \times 10^3$ (D790)
Izod impact (ft-lb/in. of notch)	12	0.4-2.2 (D256A)
Hardness	131 (Brinell)	65-85 (D2240) (shore)
Coefficient of thermal expansion (in./in. °C)	15.12×10^{-6}	$50-100 \times 10^{-6}$ (D696)
Heat deflection temperature (°F)		140-170 (D648)
Thermal conductivity (cal cm/s cm ² °C)	6.7	3.5-5.0 (C177)
Density (lb/in ³)	0.283	0.046-0.056 (D792)
Water absorption (24 hr) (%)		0.04-0.40 (D570)

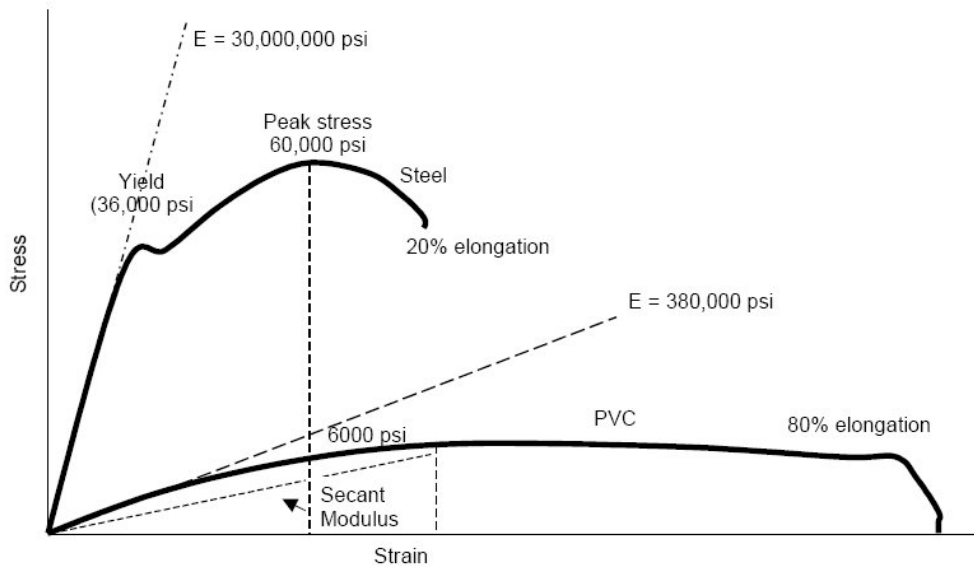


Figure 5 Schematic plot of the stress –strain curve for both steel and PVC.

When loaded, the PVC sheet piles are mostly subjected to bending forces. Under bending forces the sheet piling experiences tension in the outer flat sections (flanges) and compression in the inner flat sections (flangtes). The interlocks may be subjected to either compression or tension forces depending on the local loading conditions, however are normally being compressed together when the sheet piling is in bending.

One of the important properties of the PVC sheet pile profile is ‘Strength Rating’ or ‘Allowable Moment’. This is a function of the ‘section modulus’ and ‘allowable stress’. The section modulus (Z) describes the geometry of the sheet piling, and the allowable stress (s) defines the capability of the material when used in that specific shape. The allowable stress has to be well below the creep deformation stress over a 50-year life time. We recommend the maximum allowable stress of 3200 psi (22.1 MPa).

4.DESIGN APPROACH

4.1 GENERAL

The rest of this report will provide guidance for the safe and economical design and construction of PVC sheet pile retaining walls and floodwalls. The design procedure provides methodology for calculating the maximum bending moment, shear and deflection. In order to more accurately determine the behavior of the PVC sheet pile walls an in place instrumented test may be recommended.

Natural loads like those induced by high category hurricanes and earthquake carry an inherent risk of failure. Therefore PVC sheet pile, as any other structural material, should be used with caution in susceptible areas. This interim report only addresses the static load case. Wave action and impact loads are mentioned in general but have not been considered in the design example.

A list of definitions pertaining to sheet pile retaining walls can be found in the latest version of EM-1110-2-2504, Chapter 1. At the onset of a project details regarding the coordination, alignment selection and geotechnical considerations can be found in, Chapter 2.

4.2 GEOTECHNICAL INVESTIGATION

The design of the sheet pile starts with the investigation and complete understanding of the soil conditions. The depth and number of borings or Cone Penetrometer Tests required is a function of the detail required for the phase the project is in. All boring programs shall be conducted in accordance with EM 1110-1-1804. The corresponding soil testing shall follow the guidance from EM 1110-2-1906. Field investigation of the site and laboratory testing of the soil samples must be done irrespective of the material (steel, wood, concrete or PVC) to be used for the sheet pile wall construction.

4.3 PERFORMANCE REQUIREMENTS

The designer shall be aware of the environment and the project life expectancy where the wall is going to be installed. The material requirements will be different for walls that will be above the ground surface than those buried underground where it is used solely for seepage cut-off. Walls exposed to the UV shall have strict material requirements detailed in the contract plans and specifications. However, for buried walls and “temporary” installations (e.g. coffer dam) the UV protection requirements may not be as significant in the material selection.

4.4 ESTIMATING LOADS

The designer shall evaluate the project site and develop the loads the wall will be exposed to. The active and passive soil pressures shall be determined following the methodology in EM 1110-2-2504. Other potential loadings are, but not limited to, debris loading, surcharge loading, static water loading, wind loading, wave loading and impact loading. Due to the low Modulus of Elasticity of the vinyl material, vinyl walls have the potential of deflecting more than steel sheet pile. Although the material Modulus of Elasticity of vinyl sheet pile is as much as 80 times lower than steel, much of the difference in deflection of the structure can be made up for by the added section properties of the vinyl. In other words, a vinyl sheet pile wall will not deflect that much more than steel sheet pile as long as you are using a larger section with a higher Moment of Inertia. Much of the reduction in Modulus of Elasticity can be overcome by increasing the moment of inertia and therefore having a flexural stiffness (EI), and therefore deflection, closer to that of steel. The design of cantilever vinyl sheet piles becomes a soil structure interaction design and in most cases, deflection can govern.

4.4.1 Debris Loading – Depending on the site conditions, the driving force behind the debris load can be wind, wave action, or water current. The debris load can be modeled as a uniform distributed load over a certain length of wall. The angle of attack of the debris loading is also a consideration in the design.

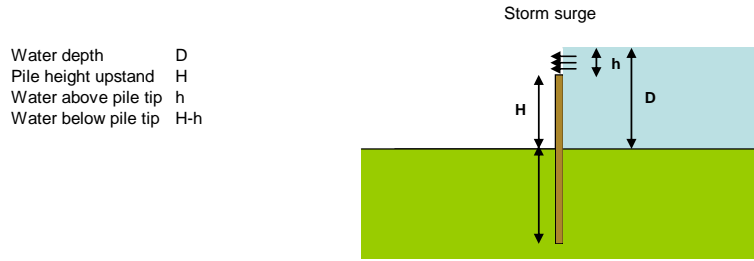
4.4.2 Surcharge Load - Surcharge loads can be analyzed as detailed in EM 1110-2-2504 chapter 4. The magnitude of the surcharge loadings are site specific and shall be determined by the design engineer.

4.4.3. Static Water Pressure –Hydrostatic water pressure is taken as the water depth multiplied by its specific weight. The designer needs to determine the mean water elevation and consider the effect of saturated soil.

4.4.4 Wind - The EM 110-2-2504 recommends 30 psf (pounds per square foot) of loading for normal wind and 50 psf for hurricanes and cyclones with wind speed up to 100 mph. If wind conditions are above 100mph refer to ANSI 52 for determining the design wind load. National Weather Service Forecast Office stipulates winds above 75 mph in hurricane categories, which produce storm surges. One of the major functional requirements of the Goose Bayou PVC sheet piling is to provide protection from daily rise and fall of tidal water and associated wind blown wave run-up. Design parameters are not based on a hurricane situation. Impending hurricane winds and tides require mandatory evacuation of residence by the local authority.

4.4.5 Storm Surge Wave Loading – The hurricane storm surges will eventually lead to wave loading of the sheet pile wall. The wave loading is a function of many factors including length of wave, height, breaking point etc. Wave forces shall be determined by a hydraulic engineer in accordance with the U.S. Army Coastal Engineering Research Center Shore Protection Manual (USAEWES 1984). The survivability of the sheet pile wall will depend on the combined loading of the static hydraulic head and the additional hydraulic head imposed by the storm surge. Table 4 shows the calculated deflections of the sheet piles made using one of the thickest PVC sections available commercially. For comparison right hand side shows the deflections for a common midsize steel sheet pile, PZ22.

Table 4 Comparison of deflections between steel and PVC sheet piles



Water depth D
 Pile height upstand H
 Water above pile tip h
 Water below pile tip H-h

PVC pile
 Moment of inertia, $I = 347 \text{ in}^4/\text{ft}$
 Young's Modulus, $E = 380,000 \text{ psi}$
 Section Modulus, $Z = 59 \text{ in}^3/\text{ft}$
 Allowable stress, $s = 3200 \text{ psi}$

Steel pile PZ 22
 Moment of inertia, $I = 84.7 \text{ in}^4/\text{ft}$
 Young's Modulus, $E = 30,000,000 \text{ psi}$
 Section Modulus, $Z = 18.4 \text{ in}^3/\text{ft}$
 Allowable stress, $s = 25000 \text{ psi}$

Surge ht(ft)	D-H(ft)	H(ft)	Deflections (in)				Deflections (in)				
			2	3	4	5	2	3	4	5	
-4			0	0	0	0	0	0	0	0	0
-3			0	0	0	0.1	0	0	0	0	0
-2			0	0	0.1	0.7	0	0	0	0	0
-1			0	0.1	0.6	3	0	0	0	0	0.2
0			0.1	0.6	2.7	10	0	0	0.1	0.5	
1			0.4	2.1	8.4	29.7	0	0.1	0.4	1.5	
2			1.2	5.9	22.9	86.6	0.1	0.3	1.2	4.4	
3			3.3	15	63.6	276.7	0.2	0.8	3.3	14.1	
4			8.2	40.4	196.9	974.3	0.4	2.1	10.1	49.8	
5			21.4	122.8	703.9	3902.5	1.1	6.3	36	199.6	
6			64.4	456.8	2884	22718.8	3.3	23.4	147.5	1161.7	

4.4.6. Impact Forces - The designer should evaluate the risk of impact as a project specific occurrence. PVC cantilever sheet pile may be susceptible to impact loads from boats or debris. If required, impact can be mitigated in a number of ways. The ideal procedure is to place the PVC wall in a position or in an alignment that would minimize. The construction of or the use of an existing submerged earthen or rock berm or gabion baskets in front of the wall that could ground a vessel prior to hitting would greatly reduce or eliminate the possibility of impact. If this cannot be satisfactorily accomplished, a method of distributing the loads over a large area of sheet piles shall be considered. A waler or cap can be used to transfer loads to an intermediate kicker pile or pillar system. There are many other ways to handle the forces applied to the sheet pile wall; it is up to the designer to consider the most economical means. Military Handbook 1025/1 (Department of the Navy 1987) provides excellent guidance in this area.

4.5 ESTIMATING DEFLECTIONS

4.5.1 Basic engineering design considerations – In this particular design scenario the sheet piles basically work as cantilever beams. For a given load condition, the stresses and deflections in beams are primarily controlled by two basic parameters: E , the modulus of elasticity of the material, and I , the moment of inertia. While E is the fundamental property of the material, I depends on the thickness and section profile of the beam. The corrugation provided by the 'Z' shape of the common sheet piles simply enhances the value of I . A cursory look at the heavier-duty sheet piles of any of the manufacturers would show higher section depths and thicker gages. The key design equation for limiting beam deflection, δ , takes the form

$$\delta = (\text{Some function of load and span})/(EI)$$

which shows that the deflection δ depends on the product EI , which is called flexural stiffness. The higher the value of EI , the lower will be the deflection. As we discussed before, because the value of E for steel is so high (i.e. 30×10^6 psi, as opposed to 0.38×10^6 psi for PVC), for the same section profile (i.e. the same moment of inertia), the deflection of the PVC sheet pile would be $30/0.38$, or approximately 80, times more than steel. However, this effect can be mitigated by the use of a vinyl sheet pile with a larger I , and therefore larger flexural stiffness (EI). The work performed by the ERDC Construction Engineering Research Laboratory, Champaign, IL, (Lampo et al., 1998) under the Construction Productivity Advancement Program (CPAR) has defined three classes of commercial sheet piles:

- A. Light duty: Minimum $EI = 2.48 \times 10^5$ kip-in²/ft
- B. Medium duty: Minimum $EI = 1.0 \times 10^6$ kip-in²/ft
- C. Heavy duty: Minimum $EI = 5.5 \times 10^6$ kip-in²/ft.

The value of moment of inertia, I , of the heavy-duty PVC sheet piles available commercially is stated to be up to approximately 347 in⁴/ft. For new installations of PVC sheet piles, $E = 380,000$ psi and $I = 347$ in⁴/ft, so EI is 1.32×10^5 kip-in²/ft.

Heights are limited by the serviceability deflection criteria determined by the designer. In this respect, the PVC sheet piling design may differ from the steel sheet piling design for cantilever structures. The section modulus should be so selected that neither the stress nor deflection exceeds the acceptable values.

The interaction between soil and the sheet pile plays an important role in determining the final deflection. "Because of the flexibility of steel sheet piling, the soil pressure for such installations differs significantly from the classical hydrostatic distribution. Generally the bending moment [and deflection] decreases with increasing flexibility of the piling. Hence the bending moment [and deflection] calculated...in a design usually regarded as too conservative." (Cernica 1995) Because of the higher flexibility of vinyl sheet piling compared to steel this effect is amplified. It is therefore important to understand that some less comprehensive calculation models and software packages can dramatically over predict deflections, and a more comprehensive software package or calculation method such as Rowe's reduction method should be used. This interaction has been defined well for steel but a full scale field testing with vinyl is still lacking.

4.6 ANALYSIS

A number of software programs are available to perform the sheet pile analysis. The Corps of Engineers software program CWALSHT is available from ERDC-ITL, Vicksburg through the Computer Aided Structural Engineering (CASE) program. This program was written specifically with steel sheet profile sections of Bethlehem Steel Corporation and United States Steel Corporation in mind. The program needs modification to allow the user to input the design parameters for PVC sheet piles. One of the commercial software for analysis of steel sheet piles is SPW911 available from Pilebuck Inc. [<http://www.pilebuck.com>]. This software allows the user to enter PVC data to compute the deflections and moment diagrams. However, the PVC analysis needs to be validated with field tests, and as stated earlier deflections can be dramatically over predicted.

5. DESIGN PROCEDURE

Once all of the previous information has been established, the design can proceed with the design methodology. The first step is to assure the systems overall stability. As discussed in EM 1110-2-2504, there are 3 modes of failure, deep-seated failure, rotational failure due to inadequate pile penetration, and failure due to overstressing of the structural members of the system. An accepted design procedure to determine the system's overall stability including minimum factors of safeties applied to the soil properties to determine the depth of penetration is detailed in chapter 5 of EM 1110-2-2504.

The designer shall base the selection of the sheet pile on deflection as well as allowable stress. The allowable bending stress for the vinyl sheet pile shall not exceed 3200 psi (22 MPa) to ensure that creep is not a problem. Additionally, the minimum thickness should be based on the dynamic load applied during driving by the respective hammer and the allowable compressive stress.

5.1 INTERLOCK STRENGTH

Opening of the interlock during driving or during its lifetime due to excessive loads can be a factor. The performance of the wall can, in rare circumstances, depend on the strength of the interlock between adjacent piles. Hence the design evaluation should look beyond the performance of the components and evaluate the response of the assembled system under full load.

The interlock configuration is the manufacturer's PVC sheet pile profile specific. Analytical study (Vaidya 2005) has shown that the existing interlock joint distributes the stress and failures are unlikely under normal driving and operating conditions.

5.2 FACTOR OF SAFETY

With engineering design, one of the most critical factors is determining the appropriate safety factors to be used, and how to apply them. The process of assigning suitable safety factors normally involves investigation of relevant codes and standards, assessment of the magnitude of risk factors and consequences of failure, and sensitivity of the wall to changes in the variable inputs. The designer is left to use their own judgment as to how to apply safety factors to balance risk and cost.

With a geotechnical structure such as a sheet piling wall, small changes in soil and environmental conditions can create large changes in loading conditions. Significant changes in soil type and compaction, water levels, soil levels, and surcharge are not uncommon and need to be considered in the designer's analysis. The consistency, magnitude and reliability of the soil data obtained prior to design can also be an important factor in choosing appropriate safety factors.

The expected service life of the structure is also an important factor in determining the required safety factors. All aspects of loading, site conditions, product performance and possible changes over the expected service life should be incorporated into the design. In general, the longer the expected life of the structure the higher the safety factor should be.

In addition, the service life of all components used in the structure should be accounted for. The life of the structure will only be as long as the shortest lasting single component. In other words, the majority of the components of the wall may have a long service life, however, if one or more inferior components are used in the system, the usable life of the structure will only be that of the inferior components.

It is also of significant importance to consider the accuracy and reliability of product specifications and parameters when determining appropriate safety factors. If a component of the structure has been specified based solely on theoretical capacities or a combination of coupon tests and calculations, there is a greater risk with the use of the product and therefore a requirement for more safety in the design. If, on the other hand, the designer is incorporating products that have been full section tested and are coupled with an in-situ performance record, such as vinyl sheet piling, there can be added confidence on behalf of the designer and a commensurate lower factor of safety.

Geotechnical structures can be extremely difficult to design and the loading parameters difficult to predict. It is therefore common for designers to use relatively high safety factors in the design process of any geotechnical structure. The designer, in combination with other project stakeholders, must always balance project costs with the amount of potential risk and determine the level of insurance obtained through safety factors appropriate for that particular project.

The following US Army Corps of Engineers Engineering Manuals (EM) provide greater detail on specific sheet piling applications and the associated standards for Factors of Safety for design.

[EM 1110-2-1614 Design of Seawalls and Bulkheads.pdf](#)

[EM 1110-2-2504 Design of Sheet Pile Walls.pdf](#)

[EM 1110-2-1617 Design of Breakwaters.pdf](#)

[EM 1110-2-2904 Design of Breakwaters.pdf](#)

[EM 1110-2-1204 Coastal Shore Protection.pdf](#)

[EM 1110-2-1206 Engineering Small Boat Basins.pdf](#)

[EM 1110-2-1913 Design & Construction of Levees.pdf](#)

[EM 1110-2-301 Floodwalls and Levees.pdf](#)

[EM 1110-2-2502 Design of Floodwalls.pdf](#)

[EM 1110-2-1601 Design of Flood Control Channels.pdf](#)

[EM 1110-2-1901 Seepage Through Levees.pdf](#)

[EM 1110-1-1804 Geotechnical Investigations.pdf](#)

[EM 1110-1-1905 Bearing Capacity of Soils.pdf](#)

[EM 1110-1-1906 Blow Count Test.pdf](#)

[EM 1110-2-1414 Water Levels and Wave Heights.pdf](#)

6. INSTALLATION

The designer must have a thorough knowledge of the actual field/soil conditions prior to installation. In most cases vinyl sheet piling is driven using the same equipment as is used for steel. In some rare instances; such as driving through dense sand, stiff clays, gravel, clamshell or coral lenses a steel mandrel sheet is recommended in order to safely install the PVC sheet pile. The designer must realize that the use of a mandrel will produce a small void between the sheet pile and the surrounding soil. This void can be backfilled with suitable materials. In the project contract documents, the designer shall determine in what manner the void shall be backfilled. The Contract coordinator shall coordinate with the vinyl manufacturer/supplier for their recommendations concerning the proper vibratory hammer and the size of the mandrel to be used.

6.1 CAPS AND WALERS

Caps and walers are often used to improve the sheet pile wall stiffness and for distributing the impact and debris loads. During installation of the caps and walers excessive tightening of the bolts should be avoided in order to prevent web crippling. The wall thickness and depth of section play an important role in protecting the wall against web crippling failure. While depth of section greatly increases moment of inertia, without an increase in wall thickness it also greatly increases the likelihood of a web crippling failure.

6.2 MAINTENANCE

PVC sheet pile installations should be inspected annually and following every major storm event. Any cracks damage or any signs of vandalisms should be addressed and proper repair should be undertaken. Manufacturer's suggested repair methods should be followed to restore the structure to its full service condition.

7. GENERAL REMARKS

Vinyl sheet pile is a viable alternative to steel pile for flood protection. This interim report has addressed the material issues raised in the ECB No. 2002-31 of 10 Oct 02 and a broad review of the design issues. More detailed analysis of the design will be addressed in the final report.

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ASTM Standard Specification for PVC

- [D 4216-03](#) Rigid Poly(Vinyl Chloride) (PVC) and Related PVC and Chlorinated Poly(Vinyl Chloride) (CPVC) Building Products Compounds, Designation:
- [D256](#) Test Method for Determining the Pendulum Impact Resistance of Notched Specimens of Plastics
- [D618](#) Practice for Conditioning Plastics for Testing
- [D635](#) Test Method for Rate of Burning and/or Extent and Time of Burning of Self-Supporting Plastics in a Horizontal Position
- [D648](#) Test Method for Deflection Temperature of Plastics Under Flexural Load
- [D696](#) Test Method for Coefficient of Linear Thermal Expansion of Plastics
- [D883](#) Terminology Relating to Plastics
- [D1435](#) Practice for Outdoor Weathering of Plastics
- [D1600](#) Terminology for Abbreviated Terms Relating to Plastics
- [D3679](#) Specification for Rigid Poly(Vinyl Chloride) (PVC) Siding
- [D4226-03](#) Test Methods for Impact Resistance of Rigid Poly(Vinyl Chloride) (PVC) Building Products
- [D4477](#) Specification for Rigid (Unplasticized) Poly(Vinyl Chloride) (PVC) Soffit
- [D4726](#) Specification for White Rigid Poly(Vinyl Chloride) (PVC) Exterior Profile Extrusions Used for Assembled Windows and Doors
- [D5260](#) Classification for Chemical Resistance of Poly(Vinyl Chloride) (PVC) Homopolymer and Copolymer Compounds and Chlorinated Poly(Vinyl Chloride) (CPVC) Compounds
- [F964-02](#) Specification for Rigid Poly(Vinyl Chloride) (PVC) Exterior Profiles Used for Fencing
- [D638M](#) Test Method for Tensile Properties of Plastics [Metric]
- [D1898](#) Practice for Sampling of Plastics
- [D3010](#) Practice for Preparing Compression-Molded Test Sample Plaques of Rigid Poly(Vinyl Chloride) Compounds