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SUBJECT: Interim Poly Vinyl Chloride (PVC) Sheet Pile Guidance.

CATEGORY: Guidance.

1. **References:**

- a. EC 1110-2-6066 “Engineering and Design: Design of I-Walls”
- b. ETL 1110-2-575 “Engineering and Design: Evaluation and I-walls”
http://www.publications.usace.army.mil/Portals/76/Publications/EngineerTechnicalLetters/ETL_1110-2-575.pdf
- c. EM 1110-2-2504 “Engineering and Design: Design of Sheet Pile Walls”
http://www.publications.usace.army.mil/Portals/76/Publications/EngineerManuals/EM_1110-2-2504.pdf
- d. Dawkins, W. P. 1991. Users guide: Computer program for design and analysis of sheet-pile walls by classical methods (CWALSHT) including Rowe’s moment reduction. Instruction Report ITL-91-1. Vicksburg, MS: U.S. Army Engineer Waterways Experiment Station.
- e. Dutta, P.K. and Vaidya, U., (2003), A study of the long-term applications of vinyl sheet piles, <http://www.crrel.usace.army.mil/library/letterreports/LR-03-19.pdf>.
- f. ASTM D4216, Standard Specification for Rigid (PVC) and Related PVC and Chlorinated Poly Vinyl Chloride (CPVC) Building Products Compounds.
- g. ASTM F964 Standard Specification for Rigid (PVC) Exterior Profiles used for Fencing and Railing.

2. **Purpose.** This bulletin transmits interim guidance for all design and use of PVC sheet pile including application, selection, design, fabrication and installation of PVC sheet pile until final guidance is placed into the appropriate engineering manuals. This guidance does not apply to Fiber Reinforced Polymer (FRP) materials.

3. **Distribution.** Unlimited.

4. **Application.** Use of PVC sheet pile should be based on an estimated cost comparison for potential cost savings and shall meet all performance requirements for the specific application, including strength, stiffness, installation, interlock integrity, durability and longevity. EC 1110-2-6066 restricts vinyl sheet pile for use in I-walls acting as a flood barrier, however this ECB relaxes those restrictions and permits PVC sheet pile walls for use as flood barrier applications subject to the guidance in the Attachment.

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5. **Update.** Interim design guidance is provided in the Attachment. New requirements will be included in the next update to EM 1110-2-2504.

6. **Point of Contact.** HQUSACE point of contact for this ECB is Mr. Richard Ludwitzke, CECW-CE, (202) 761-1580.

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Encl.
Attachment A – Design Guidance

ATTACHMENT A: Design Guidance

1. Introduction

This attachment provides guidance for the use of PVC sheet pile in USACE. Design of PVC sheet pile will be in accordance with EM 1110-2-2504 and EC 1110-2-6066 except as specified herein.

2. General Applications of PVC Sheet Piles.

Based on the intended use, applications for PVC sheet pile can be classified under three major areas:

- Ground water containment and seepage cutoff barriers
- Soil/Other Materials retaining structures
- Water control and flood risk management

In all cases, the designer must account for the foundation conditions and drivability to ensure that the sheets can be installed to required depths without voids remaining around the pile and that interlocks remain intact during installation. Interlock integrity is particularly important for structures with differential head across the sheet pile.

a. Hydraulic Cutoff Barriers (ground water or seepage).

(1) In hydraulic cutoff barriers, usually the focus is on the control of lateral migration of ground water or contaminants. The sheet piles are driven into the ground to provide a cutoff wall with the interlocks designed to achieve an effective seal.

(2) For seepage cutoff integral to concrete structures, differential movement of the structure and foundation must be carefully considered and accounted for in the design and selection of the structural system. This condition can result in transfer of structural loads to the PVC sheet pile and/or pullout of the sheet pile from the concrete footing. In addition, other conditions that would cause structure loads across the sheet pile, such as from scour or unbalanced loading, must be considered. PVC sheet pile for these purposes may be used when the differential movement of the structure and foundation can be shown to be small enough to minimize load transfer to the sheet pile or the potential structural loads can be quantified and included in the design. For structures considered critical by USACE, whose failure or poor performance may cause uncontrolled release of water and loss of life, or structures with large capital investment as determined by USACE, like dams, spillways and locks, PVC sheet pile must only be considered when relative movements of the soil and structure are expected to be below allowable design criteria values and the structural loading on the sheet pile is considered an acceptable level of likelihood by USACE with a base probability in the range of extremely unlikely.

b. Retaining Structures. When PVC sheet piles are used as a retaining wall or portion of a retaining wall, the section profile of the sheet pile, depth below grade, drainage properties and characteristics of the material/soil (both retained and driven through) and the selection of anchors, wales, caps and other reinforcements to the sheet pile, can be evaluated and selected using EM 1110-2-2504 and the guidance contained in this ECB.

c. Water Control Structures

(1) Potential water control structures covers a wide range of applications. Some common applications include: channel linings and spillways, weir walls, baffle walls and diversion structures, pond linings, levee extensions, and flood walls, including cantilever sheet pile flood walls (I-walls). Installations in this category can experience some or all of the following conditions: hurricanes and storms, surge and overtopping, wave forces, barge or vessel impact, debris and ice impact, ground movement, erosion, soil structure interaction changes and hydrodynamic forces.

(2) The design must consider and account for the uncertainty in hydraulic, environmental, and geotechnical site conditions, and the resilience of the final system to these conditions, when designing water control structures within criteria set and as determined by USACE. The final completed system must be able to function reliably over the life and not increase risk beyond what is considered acceptable by USACE. In any case, the PVC sheet pile must not be subjected to impact forces.

(3) Prior to making a decision to use PVC sheet piling as a flood wall or levee extension, a risk assessment (for design a quantitative risk assessment will be required; for planning studies a semi – quantitative risk assessment (SQRA) will be required) shall be performed. The risk assessment must evaluate all loading conditions (including flood loading, wave loading, impact loading, etc.), potential failure modes via a potential failure mode analysis (PFMA), and potential life loss and economic consequences in accordance with the “Best Practices for Dam and Levee Safety Risk Analysis” published by the USACE Risk Management Center (RMC). The risk assessment must ensure that the PVC sheet piling as a flood wall or levee extension does not pose an intolerable risk to people, property, and the infrastructure behind it. This risk assessment shall be coordinated with the RMC. In all cases, the cantilever height for any PVC sheet pile I-Wall shall be limited by calculated/estimated deflections in accordance with the limitations in ETL 1110-2-575, Appendix B.

3. Material Properties and Classification.

a. **Manufacture.** PVC sheet piles are typically manufactured by a continuous extrusion process. Rather than using virgin PVC throughout the panel thickness, which is very expensive to do correctly, manufacturers of PVC sheet piles commonly use post-industrial recycled PVC as the substrate. Typically the recycled PVC substrate forms approximately 90% of the volume. The exterior portion, which is called “capstock”, uses UV-protected, higher-quality virgin PVC to achieve resistance against weather and UV degradation. There are no ASTM standards currently available for the manufacture of PVC sheet piles specifically; however, the standards for rigid PVC exterior profiles for fencing and railing are available as ASTM F964. This ASTM is currently the closest standard to the PVC sheet pile manufacturing process

b. **PVC Classification and Mechanical Properties.** The mechanical properties and long-term performance of the PVC sheet pile are dependent on its chemical compounding. Although such compounding and fabrication are critical to the performance of the PVC sheet pile wall, the industry has yet to develop manufacturing standards. All virgin PVC used in sheet pile shall have a minimum cell classification of 1-42443-33 in accordance with ASTM D4216. The other numbers correspond to the values shown in Table A-1 in the order they are listed in the cell classification. There is no ASTM classification for the substrate. The full composite product of the substrate and cap shall meet mechanical property requirements 2 through 8 of Table A-1.

Table A-1 PVC Sheet Pile ASTM D4216 Cell Classification Requirements

Designation Order #	Properties	Cell Classification	Values
1	Type of Resin	1	PVC vinyl chloride copolymer
	Impact resistance		
2	(1) Izod Notch Testing	4	>5 ft. · lb./in
3	(2) Drop dart ASTM 4226 Procedure A	2	>1.5 in. · lb./mil
4	(3) Drop dart ASTM 4226 Procedure B	4	>3 in. · lb./mil
5	Tensile strength	4	>6500 psi
6	Modulus of elasticity*	3	>377,000 psi
7	Deflection temperature under [264 psi]	3	>158°F
8	Coefficient of linear expansion	3	<4.4×10 ⁻⁵

c. Certificate of Analysis and Warranty. All exterior portions of the PVC sheet pile, which could become exposed to the elements, shall be manufactured with a virgin compound. ASTM D4216 shall be used to ensure proper formulation and quality. PVC sheet pile shall have a certificate of analysis from an ISO 9001:2008 certified compounder indicating the minimum cell classification for the virgin PVC is 1-42443-33. A minimum 50 year manufacturer/OEM warranty for the final product shall be required in the project specifications.

d. UV Protection. When fabricating plastic products for exterior use, it is imperative that the material be protected from UV rays. Manufacturers of PVC compounds which have not been certified as meeting the recommended cell classification are required to demonstrate minimal color, physical property, and appearance change by performing tests in accordance with the ASTM D4216 specification. ASTM D4216 requires testing of new compounds for at least two years in at least three widely different climatic areas: 1) a dry hot climate (such as Phoenix, AZ), 2) a hot and humid climate (such as Miami, FL), and 3) a temperate northern climate (such as Northern Ohio or New Jersey). The virgin capstock thickness meeting the cell classification in paragraph 3.b. shall be specified to be no less than 0.015 inches at any point, unless special validated testing is performed.

4. Structural Design.

a. Bending Strength. PVC has low strength and a low modulus of elasticity relative to steel and it is also subject to creep deformation. PVC sheet pile shall be designed with an allowable bending stress of 3,200 psi (approximately half of the tensile strength of 6,500 psi) for all design loads. The allowable stress of 3,200 psi ensures that the induced stresses will remain well below the creep deformation limit for the life of the structure. Note that small increases in design stress can exponentially shorten the functional life of the sheet pile. Also note that the overstress factors listed in EM 1110-2-2504 shall not be applied to the design of PVC sheet pile.

b. Deflection. Because of the low modulus of elasticity, practical deflection limits may be exceeded well before design stress limitations are reached in the PVC sheet. Because of this, cantilevered PVC sheet pile wall designs are controlled, for the most part, by deflection rather

than stress. Typically, it is more economical to design PVC sheet pile walls as an anchored wall system. Where anchored wall systems are not possible or practical, the engineer should also give consideration to other methods of bracing the wall such as batter piles and/or combination walls made with round timber pile or other round pile materials. Designers shall design for deflection limits appropriate for the installation. The interaction between the soil and the sheet pile plays an important role in determining the final deflection. This interaction has been defined well for steel, but conclusive results from field testing with PVC is still lacking. When deflections are not critical and the stability factors of safety are high (greater than or equal to 1.5), deflections can be estimated with a simple limit equilibrium analyses. CWALSHT can be used in this case. When deflections are critical and/or the stability factors of safety are low (less than 1.5), deflections shall be computed by a soil-structure interaction analysis.

c. **Impact Forces.** PVC sheet pile has low impact resistance compared with steel and its impact resistance decreases with time. Therefore, PVC sheet pile shall not be used when large impacts during the design life are possible, i.e. large debris, vessel, or ice impact. Providing features to protect the sheet pile from impact may be practical in some situations.

d. **Corners and Intersections.** Because PVC sheet pile deflects significantly under loading, lateral forces developed by the restraint at sharp corners or at small radius bends can cause a tension failure of the interlocks. Therefore, alignment changes shall be made with large radius bends. Greater design deflections will require increased radius of bends. Sharp bends or corners shall be avoided unless deflections are limited or controlled so that tension forces are not transferred the interlock.

5. Installation

a. Typically, PVC sheet piles can be installed with the same or similar pile driving equipment that is used to drive steel sheet piling. However, given the material differences between PVC and steel sheet piling, and the wide variety of site conditions, some specialized equipment and techniques may be necessary to achieve effective results. The best choices in equipment for installation of PVC sheet piling depend on several key factors including site and soil conditions, sheet length and type and contractor experience. In dense soils or soils with obstructions, special driving measures may be required.

b. **Driving.** In general, vibratory hammers work best in granular soils, but they also work well in sandy, silty, or softer clay soils. Harder driving conditions, such as stiff or highly cohesive clays, may require a gravity drop, excavator-mounted vibratory or a fixed lead mounted vibratory hammer where some combination of light impact and pressing can be incorporated. PVC sheet piling used for I-Wall or other critical applications shall not be installed using impact hammers because of the greater likelihood of interlock damage that may result.

c. **Mandrels.**

(1) Mandrels are a type of installation equipment that provides support to PVC sheet piling in difficult driving conditions or where long and slender sheets are desired. In essence, a mandrel is a cradle, running the full length of the PVC sheet piling that is driven with the pile and then extracted after each driving operation, leaving the PVC piling in the soil. Currently there is only one supplier of mandrels for PVC sheet pile.

(2) Extraction of the mandrel results in a void between in-situ soil and the sheet-pile that may close as soil collapses against the pile. Voids or loose zones are more likely to remain in certain types of soils and with the use of imprecise construction equipment. These voids must be backfilled with suitable material as stated in 6.b.

(3) PVC sheet piling used for I-Wall or other critical applications shall not be installed using mandrels because of the formation of gaps and the possibility of voids/gaps around the surfaces of the sheet piling.

d. Other Driving Methods. Depending on the conditions, some of the following methods can be used to aid in driving or as backup when driving is too difficult.

(1) Steel spuds and similar devices can be driven along the installation line prior to and as a separate operation from driving the sheet pile which can break up obstructions. This method shall not be used for I-Wall or other critical applications.

(2) Water jetting is the direct injection of water, commonly at high pressure and volume, at the toe of the sheet piling with the purpose of displacing and saturating soil to encourage penetration of the sheet pile or removal of obstruction. Regulation is difficult and because of the possible impact to adjacent soil or structures, jetting shall not be permitted.

(3) Auger drilling is a method that usually involves a helical screw blade that displaces and loosens soil in the driving line. This method shall not be used for I-Wall or other critical applications.

(4) A trench and fill operation is used to excavate the soil (to aid in driving) or to eliminate it all together. Small “starter trenches” are often used to get below compacted fill near the surface and “toe-in” the sheets. In some cases, maximum installation efficiency is achieved by completely trenching to the desired embedment depth. Backfilling shall be performed with soil, bentonite slurry, grout, or flowable fill, depending on the depth of the trench and project specifications and requirements. Compacted backfill shall not be used due to difficulties in getting proper compaction in and around the flanges and angled webs of the sheet piling.

6. Specification and Procurement Considerations.

An USACE guide specification for PVC sheet pile does not exist at this time. The following are considerations and suggestions for inclusion into a project specification for PVC sheet pile.

a. Pulling and Redriving PVC piles.

(1) Occasionally, piles need to be pulled out of the ground. A plan for pulling sheets must be developed in advance of starting the project by the contractor as the plan will be dependent on the length of the piles and the equipment available. Redriving of PVC piles is generally discouraged but may be possible if the piles are not damaged from the pulling process. The design engineer for the project shall establish criteria for the evaluation of the pulled piles

(2) When used for seepage cutoff, piles must maintain mechanical interlock throughout their alignment. When out-of-interlock piles cannot be pulled to reestablish interlocks, repair methods such as overlapping of piles and/or grout columns must be designed to provide an equivalent barrier. Remedial measures such as this will be designed by the design engineer.

b. Void Backfill. Voids shall be filled in. The functional requirements of the PVC wall and the soil conditions will be used to determine if the backfill method will be bentonite slurry, grout, flowable fill or earthen material.

c. Submittals by the Contractor. The following paragraphs are necessary submittals from the contractor prior to construction;

(1) Shop Drawings. The Contractor must provide cut sheets, shop drawings and manufacturer developed specifications for any materials supplied as a part of any construction project under the shop drawing submittal process. The Contractor will also be required to submit the qualifications of the manufacturer and submit a record of previous projects with similar conditions and functions where the product has been used successfully.

(2) Equipment Descriptions and Installer Qualifications.

(a) Prior to the commencement of work, the Contractor shall be required to submit for approval a written statement addressing the appropriate installation equipment, tools, and driving method as dictated by the soil conditions, including driving aids. Typical driving aids might be the use of a mandrel, an auger, a pre-punch tool such as an I-beam or even a heavy duty steel sheet pile driven ahead of a light duty pile to clear the way for the lighter pile section.

(b) Qualifications for the Contractor and the supplier of the mandrel shall be required. The Contractor shall be required to have experience with driving procedures for installing PVC sheets in similar soil conditions. In addition, the installer is required to use the PVC sheet pile manufacturer's specifications and suggestions regarding equipment and driving aids.

(3) Materials test certificates and warranties. Prior to delivery, the Contractor shall be required to submit the material certificates indicating conformance to the project specifications. Sheet pile materials must be certified by the manufacturer to meet the specified mechanical and section property requirements of this specification as follows:

(a) Certificate of analysis from an ISO 9001:2008 certified compounder indicating that virgin material meets the cell classification 1-4244-33 in accordance with ASTM D4216 and that the full sheet pile section meets mechanical requirements 2 through 8 of Table A-1.

(b) Material certification indicating that the material being received by the Contractor is in conformance with the geometric and material requirements outlined in the specifications.

(c) 50 year manufacturer's/OEM warranty. Reseller or outsourcer warranties are not sufficient.

(4) Delivery storage and handling. Storage and handling instructions will vary by manufacturer, product type, and shape. Storage and handling instructions shall be provided by the manufacturer and followed by the Contractor.