Sheet Pile as a Channel Lining Material

Headache or Blessing!

Floodplain Management Association Conference

September 9, 2015
BEFORE
Sheet Pile - Typical Uses

Sheet Pile - Retaining Structures
Sheet Pile - Seepage Cutoff Wall
Sheet Pile – Port and Dock Structures
Sheet Pile – Typical Uses

Sheet Pile – Coffer Dam Structures
Sheet Pile - Typical Uses

Sheet Pile – Grade Control and Weir Structures
Sheet Pile – Security Wall Structures
Sheet Pile - Typical Uses

Sheet Pile – Flood Wall Structures
Common sheet pile material types include:

- Concrete
- Steel
- Aluminum
- Plastic: PVC – vinyl or FRP – Fiber Reinforced Polymer, AKA: Fiberglass
- Wood (but fairly rare as a true sheet pile)
Concrete Sheet Pile – Talbert Channel Outlet, Huntington Beach, CA

Sheet piles shown are 4 feet wide by 2 feet thick by 30 feet long – tongue and groove – each pile weighed 36,000 lbs

New pre-stressed conc. sheet piles now out on the market are much more stream-lined

Figure 2 Concrete Sheet Pile
Sheet Piles shown here are a type of Cold-Formed Steel Pile no longer offered on the market, but others like it are.
Aluminum Sheet Pile, Location Unknown

Piles shown here are a Crane Materials International (CMI) product
PVC/Vinyl Sheet Pile – Bolsa Chica Wetlands, Huntington Beach, CA

Piles shown here are also a CMI Product
Concrete sheet piles generally have tongue-and-groove or no interlock
Sheet Pile Basics

Sheet Pile Interlocks

Steel

There are several interlock types for steel sheet pile depending on the manufacturer and if the sheet pile is Cold-Formed or Hot-Rolled.
Sheet Pile Basics

Sheet Pile Interlocks

Steel

Cold Formed Pile Interlock
Sheet Pile Basics

Sheet Pile Interlocks

Steel

Hot Rolled Pile Interlocks

There are also sheet pile made for shoring that have no interlocks
Sheet Pile Basics

Sheet Pile Interlocks

Steel

There are also sheet piles made for shoring that have no interlocks. They simply overlap them.
Sheet Pile Basics

Sheet Pile Shapes

Steel

There are several sheet pile shapes for steel sheet pile.

- **U or Channel-Shaped** – PU, AU, etc.
- **Pan, Arch, or Hat-Shaped** – SKL, SKS
- **Z-Shaped** – AZ, PZ, PZC, etc.
- **Combi-Wall** with Circular King Piles - PAZ
- **Straight or Flat-Shaped** – AS, PS, etc.
- **Combi-Wall** with H (King) Piles - HZ
Sheet Pile Basics

Steel Sheet Pile – Hot-Rolled vs. Cold-Formed

Hot-Rolled sheet piles are formed from glowing hot steel ingots where the shapes and interlocks are extruded and/or formed while hot, then allowed to cool. Due to the manufacturing process, these piles can be made very thick and strong, and interlocks are generally stronger.

Cold-Formed sheet piles are stamped, folded, or bent into shape out of steel sheets that have already cooled. Due to the manufacturing process, these piles can be made very quickly and at much less cost.
Sheet Pile Basics

Steel Sheet Pile – Hot-Rolled vs. Cold-Formed

Due to the manufacturing process, these piles can be easily made from thicker and stronger – higher strength steels up to 65 ksi and ¾” thick.

The hot-rolling manufacturing process creates a more uniform steel pile.

Due to the manufacturing process, these piles can only be made from lighter or thinner steel sheets that the manufacturer’s machinery can bend and fold – 65 ksi & ½”

The cold-formed process places pre-stressing into the steel where the steel is bent and formed into its final shape. Some say it makes the pile stronger at the bends, some say it makes it weaker, brittle, and prone to faster corrosion.
Sheet Pile Basics
Steel Sheet Pile – Hot-Rolled vs. Cold-Formed

Due to the manufacturing process, the pile interlocks are tighter and made to a higher tolerance with less leakage and sediment loss through the interlock.

Tighter interlock reduces interlock play which reduces movement and lean during driving and interlock strength allows for driving in stiffer, harder conditions.

Due to the manufacturing process, the pile interlocks allow for greater swing and tighter curves, but can be brittle at bends.

Cold-formed sheet piles are available in many different lengths, shapes and thicknesses and generally more available and easier to meet demand (does not require as much special order as hot-rolled).
Sheet Pile Basics

Aluminum Sheet Pile

The PZH-159 has a Section Modulus of 17in³/ft and has an allowable moment of 27,625 ft-lb/ft.

This is equivalent to a Skyline Steel cold-formed SCZ 17N – Z-Section that has a Section Modulus of 16.87 in³/ft and an allowable moment of 35,145 ft-lb/ft. Its width is also 28.5 inches, so it will also cover almost twice the distance.

CMI AlumiGuard PZH-159

- Aluminum is about ½ the strength of steel and is about twice as expensive.
- Aluminum oxidizes far more quickly than steel, but creates a hard self healing oxidized coating. If the oxidation is constantly rubbed off, the exposed aluminum will oxidize quickly, but with metal loss.
- Structural Al 7075 is about 1.5 stronger than marine grade AL 6061, but corrodes far more quickly, and therefore, is not used in marine applications.
Sheet Pile Basics

Plastic Sheet Pile

- Plastic sheet piles now have a design life of about 50-years
- Excellent corrosion resistant qualities
- The UC-95 (fiberglass) has SM = 58.8 in³/ft and max. moment of 48,750 ft-lb/ft
- Good in soft soils and retained heights up to 10 feet, alignment issues in hard soils
- Must use a vibratory hammer for installation and can be expensive
- California Coastal Commission had problems in the past approving vinyl (PVC) piles in the Coastal Zone
Fiber Reinforced Polymer (FRP) Sheet Pile Cap good against corrosion from marine environments
The Orange County Flood Control District has utilized the following sheet pile types:

- Steel – both Cold Formed and Hot Rolled sections (only Z-Sections, no U-Sections)
- Concrete – with epoxy coated rebar
- Vinyl – State and Feds installed PVC piles adjacent to one of our flood channels but only as a seawater intrusion barrier
The Orange County Flood Control District has been actively using sheet pile as a channel lining material since 1987.

Since 1987, OCFCD has installed approximately 82,000 LF of sheet pile channel wall or about 15.5 miles.

Approximately 130 million pounds of steel and about 10 million pounds of concrete.

- 1,100 LF of concrete sheet piles
- 80,900 LF of steel sheet piles
- 68,500 LF within tidally influenced channels
- 13,500 LF in alluvial, sandy, cobble laden soils
Why has the Orange County Flood Control District used so much sheet pile?

Orange County is a coastal county with 42 miles of coastline and about 30 miles of tidally influenced flood control channels.
Right of way for most of Orange County's flood control channels was acquired 50 to 100 years ago when the area was mainly agriculture and open space. Now most of Orange County's flood control facilities are lined with residential and commercial development making it difficult if not impossible to acquire additional right of way to widen channel facilities.

Other than San Francisco County/City, Orange County is the most densely populated County in California with 3.15 million residents and a density of about 4000 people per square mile as of July 1, 2014.
Advantages of Sheet Pile as a Channel Lining Material

• Sheet Pile can be installed from atop a levee without heavy equipment entering the channel or working from the channel bed

• Because of this, sheet pile can be installed year around – no need to worry about blocking channel flow in the storm season

• If your not engaged in construction in the channel (AKA: Jurisdictional area), you do not need a permit – Coastal Zone and Endangered Species are the exceptions
Advantages of Sheet Pile as a Channel Lining Material (continued)

- If you conduct excavation operations from the top of the levee (outside Corps jurisdictional area), you do not need a Section 401 or 404 permit since excavation is not regulated (just discharge of fill or dredge material)

- If you don’t excavate the material, you don’t need a California Department of Fish and Wildlife permit either

- If you widen the channel by simply excavating, you create wetlands.
Advantages of Sheet Pile as a Channel Lining Material (continued)

- Use of a Giken Press-In Pile Driver can reduce your environmental footprint to the width of the sheet pile itself

Emergency sheet pile project on failing levee
Advantages of Sheet Pile as a Channel Lining Material (continued)

- The placement of heavy equipment on a failing levee can be avoided by use of a Giken Driver because the driver sits on the piles themselves and not on the top of the levee – piles are delivered to the driver by a cart that rides along the piles.
Note how driver and crane sit atop the previously driven sheet piles and not on the levee (which was in bad shape and could not support the load of heavy equipment)
Advantages of Sheet Pile as a Channel Lining Material (continued)

• Channel dewatering is not necessary – great advantage for tidally influenced channels – subsidence of adjacent properties can be avoided

• Pour soil conditions can be overcome by simply extending sheet pile length and increasing section modulus – soil bearing load is not a factor

• Soft peats, clays, and silts are actually easier for sheet pile driving

• Sheet piles can many times be removed just as easily as they were installed using a vibratory hammer – sheet pile height and depth can be adjusted

• That’s why many contractors like sheet pile as a shoring or cut-off wall material to use over and over
Disadvantages of Sheet Pile as a Channel Lining Material

• Tremendous soil loss through concrete sheet pile joints that may require a follow up project to seal the joints.

• Rebar in concrete piles are still subject to corrosion

• Embedded fence posts can cause significant damage in the top of concrete piles

• Concrete piles are generally much thicker and harder to drive than other piles which either causes significant shaking and noise (vibratory and impact hammers) or must be water jetted into place which can cause its own set of issues.
Sand boil caused by water jetting activity associated with sheet pile driving

If allowed to continue, could have significantly jeopardized the structural integrity of the levee due to soil particle loss and creation of voids under levee embankment.
• Concrete sheet pile cost four times as much per foot of channel wall than steel sheet piles to construct (initial cost).

• Construction process for concrete piles is far more disruptive to the adjacent community than other pile types.

• Extremely difficult to drive concrete piles in sandy cobble laden or stiff clayey soils

• The nice flat face of concrete piles provide a good canvas for graffiti.
• Steel piles are very much subject to corrosion especially in a marine environment.

• Cathodic protection (both impressed or galvanic) will not protect your portion of sheet pile that is exposed to the atmosphere. Only a corrosion resistant coating can protect that portion of your steel.

• Corrosion is almost always the worst within the splash zone (wet/dry zone). This, many times, is close to your sheet pile’s maximum moment.

• Steel does not corrode evenly – if using a sacrificial steel design, use worst case (splash zone) scenario.
Steel sheet piles require constant maintenance to ensure the integrity of the corrosion resistant coatings, or just replace the sheet piles as needed.
• Installation and maintenance of cathodic protection systems can be a significant expense and should be accounted for in your construction as well as maintenance budget.

• Many people do not appreciate the aesthetic beauty of rectifier cabinets behind their homes.
You should plan on possible environmental impacts and mitigation for installation of galvanic anodes within a channel invert. You should also account for the corresponding spoils from the excavation!

Careful of your anode composition. Some anodes may have lead components in them that environmental regulators don’t like.
Cathodic protection systems (especially impressed current systems) can be subject to vandalism.

CP Rectifier Cabinet with transformer

Same rectifier cabinet months later without transformer – cause it was stolen.
Aluminum anodes with cut off and stolen copper anode lead wires
Experience Talking Here
Over the past 25-years, OCFCD has had contractors use many different types of pile driving equipment: water jetting, diesel impact hammers, vibratory hammers, and ABI and Giken Reaction Base Press-In Pile Drivers with and without pre-drilling equipment.

In my experience, this依次 is the order of magnitude of the most disruptive driving method to the surrounding neighborhoods: Most disruptive Pile Driver of Them All!
In stiff clays and sandy, cobbled soil, you’ll save yourself a lot of heartache by predrilling just prior to pile driving – get an expert opinion from your Geotechnical Engineer first.
If you plan on using concrete, steel, or aluminum sheet pile, get a corrosion site report from a corrosion engineering firm first with design recommendations. Not all project sites need corrosion countermeasures or may only need minor adjustments in the design.

Other sites may need a full bore coating and CP System design.
If not designed properly, a cathodic protection system can actually cook the coating right of the sheet pile – “Cathodic Disbondment!”

Some corrosion resistant coatings perform very poorly in conjunction with CP systems and are prone to cathodic disbondment.

Some corrosion resistant coatings perform poorer or better depending upon the color you choose.

Some coatings are far better in direct sunlight than others and some are far more abrasion resistant than others. It is highly recommended that you retain the services of an independent corrosion coatings designer to assist with your design. Product reps will generally want to sell you on their product regardless if it’s the best fit or not; it’s there job.
Always, always, always!!! hire a NACE Certified Coatings Inspector to inspect the application of the corrosion resistant coatings on your sheet pile at the plant and in the field. This may save you million$. 
If you choose a coating application system that requires more than one coat, it is highly recommended that you use a different color for the base coat than the top coat, and a different color for every coat in between.

This will make it much easier for your inspector to ensure proper application and much harder for the applicator to skimp on coating thickness and drying times.
Remember steel corrodes even in concrete. Design it right the first time for its intended design life.

When bidding a sheet pile job, ensure that you specify at least two or three different sheet pile products from different manufacturers if possible. The direct competition may save you million$.

If possible, don’t limit the contractor to just one pile driving method for the project. Allowing different driving methods may increase competition and bidding.

Allow ample time for sheet pile ordering, manufacturing, and delivery to your jobsite. It may take three to four months just to get your sheet pile delivered.

Ensure adequate time for pile installation. Cutting the time short may require the contractor to employ two or three drivers and pile driving teams significantly increasing project costs.

If employing impact or diesel pile driving, ensure your contractor utilizes an adequate pile driving template to ensure proper pile alignment.
Sheet pile manufacturers and their distributors have been asking us to have the project bidders specify on their bid forms what sheet pile their bid is based on. This cuts down on the winning bidders going back to manufacturers and trying to cut a better deal by threatening to go to another manufacturer which is no benefit to the public agency.

The listing of the product as part of the bid has allowed the manufacturers to give us their best price up front which is a distinct advantage for the public agency.
Our agency has been using the Corps design manuals EM 1110-2-1614, Design of Seawalls and Bulkheads and EM 1110-2-2504, Design of Sheet Pile Walls and their software “CWALSHT”.

By designing our levee sheet pile to Corps design criteria it is much easier to acquire acceptance by Corps staff for the PL 84-99 programs, Levee Safety program, and FEMA levee certification.

Remember – sheet piles are not bearing piles. They are a retaining structure. If the pile encounters refusal, you need to evaluate if the pile depth is adequate to resist the active lateral soil load of its retained load/soil height. Sometimes the adjacent piles can carry the tributary load or the use of a waler can distribute the load among many piles.

Sticking a whole bunch of sheet pile in the ground could disrupt groundwater flow. You may need the assistance of a hydro-geologist to assist you with your design. Our agency has installed many groundwater monitoring wells to monitor the affect of our sheet pile walls on shallow groundwater before and after installation. We have also provided windows for groundwater movement, by leaving every fourth sheet pile shorter than the rest and adjusting the sheet pile structural section and length to accommodate.
Rule-of-Thumb in Sheet Pile Design:
For every foot of retained height, you want two feet of embedment!

Questions