Design of Sheet Pile Walls

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Chapter 1
Introduction

1-1. Purpose

The purpose of this course is to provide guidance for the safe design and economical construction of sheet pile retaining walls and floodwalls. This course does not prohibit the use of other methods of analysis that maintain the same degree of safety and economy as structures designed by the methods outlined herein.

1-2. Applicability

This course applies to all design elements, major subordinate commands, districts, laboratories, and field operating activities (FOA) having civil works responsibilities.

1-3. References, Bibliographical and Related Material

a. References pertaining to this course are listed in Appendix A. Additional reference materials pertaining to the subject matter addressed in this course are also included in Appendix A.

b. Several computer programs are available to assist in applying some of the analytical functions described in this course.

(1) CWALSHT - Performs many of the classical design and analysis techniques for determining required depth of penetration and/or factor of safety and includes application of Rowe's Moment Reduction for anchored walls. (CORPS Program X0031)

(2) CWALSSI - Performs soil-structure interaction analysis of cantilever or anchored walls (Dawkins 1992).

1-4. Scope

Design guidance provided herein is intended to apply to wall/soil systems of traditional heights and configurations in an essentially static loading environment. Where a system is likely to be required to withstand the effects of an earthquake as a part of its design function, the design should follow the processes and conform to the industry standards and requirements.

1-5. Definitions

The following terms and definitions are used herein.

a. Sheet pile wall: A row of interlocking, vertical pile segments driven to form an essentially straight wall whose plan dimension is sufficiently large that its behavior may be based on a typical unit (usually 1 foot) vertical slice.

b. Cantilever wall: A sheet pile wall which derives its support solely through interaction with the surrounding soil.

c. Anchored wall: A sheet pile wall which derives its support from a combination of interaction with the surrounding soil and one (or more) mechanical devices which inhibit motion at an isolated point(s). The design procedures described in this course are limited to a single level of anchorage.

d. Retaining wall: A sheet pile wall (cantilever or anchored) which sustains a difference in soil surface elevation from one side to the other. The change in soil surface elevations may be produced by excavation, dredging, backfilling, or a combination.

e. Floodwall: A cantilevered sheet pile wall whose primary function is to sustain a difference in water elevation from one side to the other. In concept, a floodwall is the same as a cantilevered retaining wall. A sheet pile wall may be a floodwall in one loading condition and a retaining wall in another.

f. I-wall: A special case of a cantilevered wall consisting of sheet piling in the embedded depth and a monolithic concrete wall in the exposed height.

g. Dredge side: A generic term referring to the side of a retaining wall with the lower soil surface elevation or to the side of a floodwall with the lower water elevation.

h. Retained side: A generic term referring to the side of a retaining wall with the higher soil surface elevation or to the side of a floodwall with the higher water elevation.

i. Dredge line: A generic term applied to the soil surface on the dredge side of a retaining or floodwall.

j. Wall height: The length of the sheet piling above the dredge line.

k. Backfill: A generic term applied to the material on the retained side of the wall.

l. Foundation: A generic term applied to the soil on either side of the wall below the elevation of the dredge line.

m. Anchorage: A mechanical assemblage consisting of wales, tie rods, and anchors which supplement soil support for an anchored wall.

(1) Single anchored wall: Anchors are attached to the wall at only one elevation.

(2) Multiple anchored wall: Anchors are attached to the wall at more than one elevation.

n. Anchor force: The reaction force (usually expressed per foot of wall) which the anchor must provide to the wall.

o. Anchor: A device or structure which, by interacting with the soil or rock, generates the required anchor force.

p. Tie rods: Parallel bars or tendons which transfer the anchor force from the anchor to the wales.

q. Wales: Horizontal beam(s) attached to the wall to transfer the anchor force from the tie rods to the sheet piling.

r. Passive pressure:
The limiting pressure between the wall and soil produced when the relative wall/soil motion tends to compress the soil horizontally.

s. Active pressure: The limiting pressure between the wall and soil produced when the relative wall/soil motion tends to allow the soil to expand horizontally.

t. At-rest pressure: The horizontal in situ earth pressure when no horizontal deformation of the soil occurs.

u. Penetration: The depth to which the sheet piling is driven below the dredge line.

v. Classical design procedures: A process for evaluating the soil pressures, required penetration, and design forces for cantilever or single anchored walls assuming limiting states in the wall/soil system.

w. Factor of safety:

(1) Factor of safety for rotational failure of the entire wall/soil system (mass overturning) is the ratio of available resisting effort to driving effort.

(2) Factor of safety (strength reduction factor) applied to soil strength parameters for assessing limiting soil pressures in Classical Design Procedures.

(3) Structural material factor of safety is the ratio of limiting stress (usually yield stress) for the material to the calculated stress.

x. Soil-structure interaction: A process for analyzing wall/soil systems in which compatibility of soil pressures and structural displacements are enforced.

Chapter 2
General Considerations

2-1. Coordination

The coordination effort required for design and construction of a sheet pile wall is dependent on the type and location of the project. Coordination and cooperation among hydraulic, geotechnical, and structural engineers must be continuous from the inception of the project to final placement in operation. At the beginning, these engineering disciplines must consider alter- native wall types and alignments to identify real estate requirements. Other disciplines must review the pro- posed project to determine its effect on existing facilities and the environment. Close coordination and consultation of the design engineers and local interests must be maintained throughout the design and construction process since local interests share the cost of the project and are responsible for acquiring rights-of-way, accomplishing relocations, and operating and maintaining the completed project. The project site should be subjected to visual inspection by all concerned groups throughout the implementation of the project from design through construction to placement in operation.

2-2. Alignment Selection

The alignment of a sheet pile wall may depend on its function. Such situations include those in harbor or port construction where the alignment is dictated by the water source or where the wall serves as a tie-in to primary structures such as locks, dams, etc. In urban or industrial areas, it will be necessary to consider several alternative alignments which must be closely coordinated with local interests. In other circumstances, the alignment may be dependent on the configuration of the system such as space requirements for an anchored wall or the necessary right-of-way for a floodwall/levee system. The final alignment must meet the general requirements of providing the most viable compromise between economy and minimal environmental impact.

a. Obstructions. Site inspections in the planning phase should identify any obstructions which interfere with alternative alignments, or which may necessitate special construction procedures. These site inspections should be supplemented by information obtained from local agencies to locate underground utilities such as sewers, water lines, power lines, and telephone lines. Removal or relocation of any obstruction must be coordinated with the owner and the local assuring agency. Undiscovered obstructions will likely result in construction delays and additional costs for removal or relocation of the obstruction. Contracts for construction in congested areas may include a requirement for the contractor to provide an inspection trench to precede pile driving.

b. Impacts on the surrounding area. Construction of a wall can have a severe permanent and/or temporary impact on its immediate vicinity. Permanent impacts may include modification, removal, or relocation of existing structures. Alignments which require permanent relocation of residences or businesses require additional lead times for implementation and are seldom cost effective. Particular consideration must be given to sheet pile walls constructed as flood protection along waterfronts. Commercial operations between the sheet pile wall and the waterfront will be negatively affected during periods of high water and, in addition, gated openings through the wall must be provided for access. Temporary impacts of construction can be mitigated to some extent by careful choice of construction strategies and by placing restrictions on construction operations. The effects of pile driving on existing structures should be carefully considered.

c. Rights-of-way. In some cases, particularly for flood protection, rights-of-way may already be dedicated. Every effort should be made to maintain the alignment of permanent construction within the dedicated right-of-way. Procurement of new rights-of-way should begin in the feasibility stage of wall design and should be coordinated with realty specialists and local interests. Temporary servitudes for construction purposes should be determined and delineated in the contract documents. When possible, rights-of-way should be marked with permanent monuments.

d. Surveys. All points of intersection in the alignment and all openings in the wall should be staked in the field for projects in congested areas. The field survey is usually made during the detailed design phase. The field survey may be required during the feasibility phase if suitability of the alignment is questionable. The field survey should identify any overhead obstructions, particularly power lines, to ensure sufficient vertical clearance to accommodate pile driving and construction operations. Information on obstruction heights and clearances should be verified by the owners of the items.

2-3. Geotechnical Considerations

Because sheet pile walls derive their support from the surrounding soil, an investigation of the foundation materials along the wall alignment should be conducted at the inception of the planning for the wall. This investigation should be a cooperative effort among the structural and geotechnical engineers and should include an engineering geologist familiar with the area. All existing databases should be reviewed. The goals of the initial geotechnical survey should be to identify any poor foundation conditions which might render a wall not feasible or require revision of the wall alignment, to identify subsurface conditions which would impede pile driving, and to plan more detailed exploration required to define design parameters of the system. Geotechnical investigation requirements are discussed in detail in Chapter 3 of this EM.

2-4. Structural Considerations

a. *Wall type*. The selection of the type of wall, anchored or cantilever, must be based on the function of the wall, the characteristics of the foundation soils, and the proximity of the wall to existing structures.

(1) Cantilever walls. Cantilever walls are usually used as floodwalls or as earth retaining walls with low wall heights (10 to 15 feet or less). Because cantilever walls derive their support solely from the foundation soils, they may be installed in relatively close proximity (but not less than 1.5 times the overall length of the piling) to existing structures. Typical cantilever wall configurations are shown in Figure 2-1.

(2) Anchored walls. An anchored wall is required when the height of the wall exceeds the height suitable for a cantilever or when lateral deflections are a consideration. The proximity of an anchored wall to an existing structure is governed by the horizontal distance required for installation of the anchor (Chapter 5). Typical configurations of anchored wall systems are shown in Figure 2-2.

b. *Materials*. The designer must consider the possibility of material deterioration and its effect on the structural integrity of the system. Most permanent structures are constructed of steel or concrete. Concrete is capable of providing a long service life under normal circumstances but has relatively high initial costs when compared to steel sheet piling. They are more difficult to install than steel piling. Long-term field observations indicate that steel sheet piling provides a long service life when properly designed. Permanent installations should allow for subsequent installation of cathodic protection should excessive corrosion occur.

(1) Heavy-gauge steel. Steel is the most common material used for sheet pile walls due to its inherent strength, relative light weight, and long service life. These piles consist of interlocking sheets manufactured by either a hot-rolled or cold-formed process and con- form to the requirements of the American Society for Testing and Materials (ASTM) Standards A 328 (ASTM 1989a), A 572 (ASTM 1988), or A 690 (ASTM 1989b).
Piling conforming to A 328 are suitable for most installations. Steel sheet piles are available in a variety of standard cross sections. The Z-type piling is predominantly used in retaining and floodwall applications where bending strength governs the design. When interlock tension is the primary consideration for design, an arched or straight web piling should be used. Turns in the wall alignment can be made with standard bent or fabricated corners. The use of steel sheet piling should be considered for any sheet pile structure. Typical configurations are shown in Figure 2-3.

(2) Light-gauge steel. Light-gauge steel piling are shallow-depth sections, cold formed to a constant thick- ness of less than 0.25 inch and manufactured in accordance with ASTM A 857 (1989c). Yield strength is dependent on the gauge thickness and varies between 25 and 36 kips per square inch (ksi). These sections have low-section moduli and very low moments of inertia in comparison to heavy-gauge Z-sections. Specialized coatings such as hot dip galvanized, zinc plated, and aluminized steel are available for improved corrosion resistance. Light-gauge piling should be considered for temporary or minor structures. Light-gauge piling can be considered for permanent construction when accompanied by a detailed corrosion investigation. Field tests should minimally include PH and resistivity measurements. See Figure 2-4 for typical light-gauge sections.

(3) Wood. Wood sheet pile walls can be constructed of independent or tongue-and-groove interlocking wood sheets. This type of piling should be restricted to short- to-moderate wall heights and used only for temporary structures. See Figure 2-5 for typical wood sections.

(4) Concrete. These piles are precast sheets 6 to 12 inches deep, 30 to 48 inches wide, and provided with tongue-and-groove or grouted joints. The grouted-type joint is cleaned and grouted after driving to provide a reasonably watertight wall. A bevel across the pile bottom, in the direction of pile progress, forces one pile

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