Selection of Excavation Support Systems - Advantages and Disadvantages

American Society of Highway Engineers - Delaware Valley Section

Technical Session

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Selection of Excavation Support Systems - Advantages and Disadvantages

- Historically general contractors or specialty sub-contractors have been responsible for selection, design, and construction of Excavation Support Systems (ESS)
- Recent trend – consultants and agencies specifying specific ESS systems, but not necessarily the best fit ESS system
- Solution – education, mentors, design & field experience

What is the purpose of an Earth Retaining Structure?

- To create a safe excavation into which a permanent structure can be built or to be the permanent earth retaining structure itself
- Selection type and method of installation are dependent upon:
  - Type of soil, ground conditions (soil, rock)
  - Elevation of groundwater, dewatering requirements & effects
  - Depth of supported excavation
  - Proximity to existing structures (surcharges)
  - Cost
  - Time

Pre-selection/Pre-design

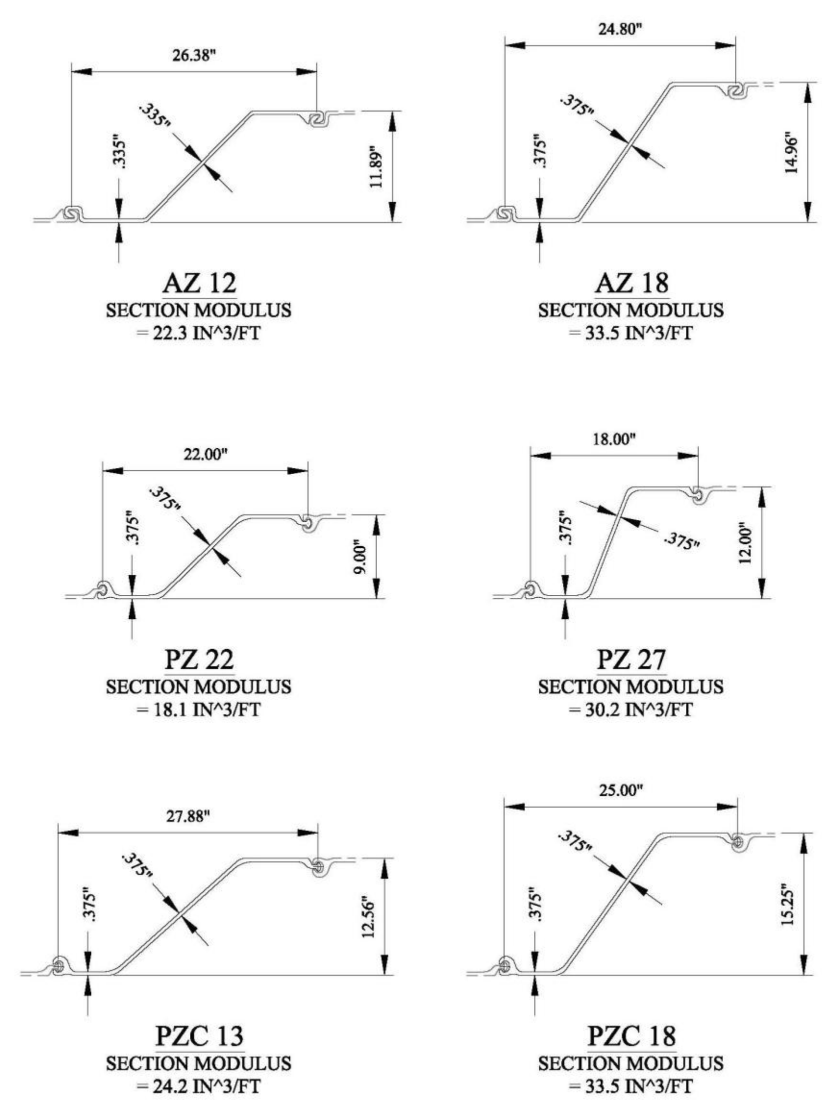
- Obtain soil boring data
- Survey existing structure and utilities
- Review data available from libraries, utility companies, bldg. departments, etc.
- Examine site and existing conditions
- Prepare sketches
- Determine allowable deformation
- Determine expected loads (soil, water, traffic, constr. equipment, material storage, adjacent structures)
- Understand owner’s design requirements (DOT, RR, ASD, LRFD)

Types of Excavation Support Systems

- Steel Sheet Piling
- Slide Rail Systems
- Soldier Pile Walls w/ Horizontal Lagging
- Micropile Walls
- Secant Pile Walls
- Deep Soil Mixing Walls
- Soil Nail Walls
- Vertical Wood Sheeting Walls
- Trench Boxes and Shielding
- Diaphragm Walls (Slurry Walls)
- Underpinning

Steel Sheet Piling

- Hot-rolled or cold-formed
- Variety of shapes and weights
- Interlocks between sections
- Driven into position with conventional pile driving equipment before excavation commences
- Driven in waves



Steel Sheet Piling

Steel Sheet Piling

- Advantages
  - Useful in areas with high groundwater levels
  - Desirable when retained soils are soft and loose
  - Pull or extract the SSP after use, recycle for future project
- Disadvantages
  - Not recommended in soils with obstructions or hard layers of soil
  - High material costs

Slide Rail Systems

- Modular ESS comprised of heavy duty shoring panels supported by vertical, multi-track rails
- Panels are advanced or slid downward as excavation progresses toward subgrade
- Panels are available in heights 4 to 8 feet and lengths 8 to 20 feet
- Supported by two or more levels of cross struts

Slide Rail Systems

- Advantages
  - Used for relatively narrow excavations
  - "Dig and Push" method
  - Typically rented rather than purchased
  - Design can be provided by system's manufacturer
- Disadvantages
  - Not practical where obstructions expected (ex. Utilities)
  - Proprietary systems with unpublished design parameters

Soldier Pile Walls with Horizontal Lagging

- Consists of vertical members called soldier piles (or soldier beams) @ 6′ to 10′ o.c.
- Horizontal members span between beams to retain soil
- Excavations up to 12′ - Cantilever
- Excavations > 12′ – Braced
- Most common in cut situations or top down construction
- Soldier piles are typically HP piles or WF sections, but can also be pipe piles

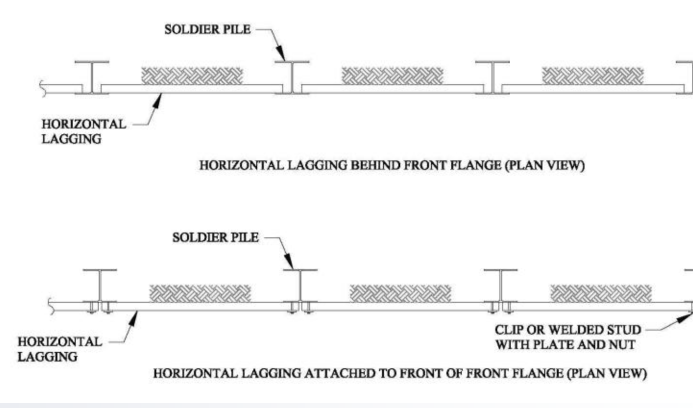
Soldier Pile Walls with Horizontal Lagging

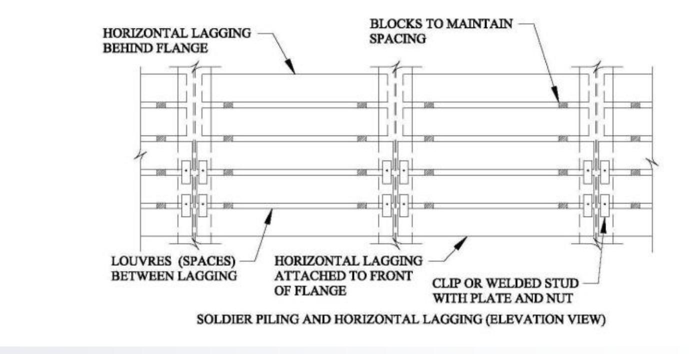
Soldier Pile Walls - Installation

- Soldier beams man be installed using conventional pile driving equipment or installed in drilled or augered holes
- When using drilled-in soldier beams, fill entire hole completely with lean mix concrete or flowable fill (f'c = 100 psi)
- Typically, pile driving is most economical, but drilling-in soldier beams on small projects may be more economical
- Augered holes eliminate noise and reduce vibration in urban environments

Horizontal Lagging

- Typically 3” nom. Thickness timber lagging
- Installed behind flanges or attached front flanges
- Installed in 5’ max. vertical lifts
- Louvers – 1.5” to 2” vertical space between boards
- Retained soil should be tight against lagging





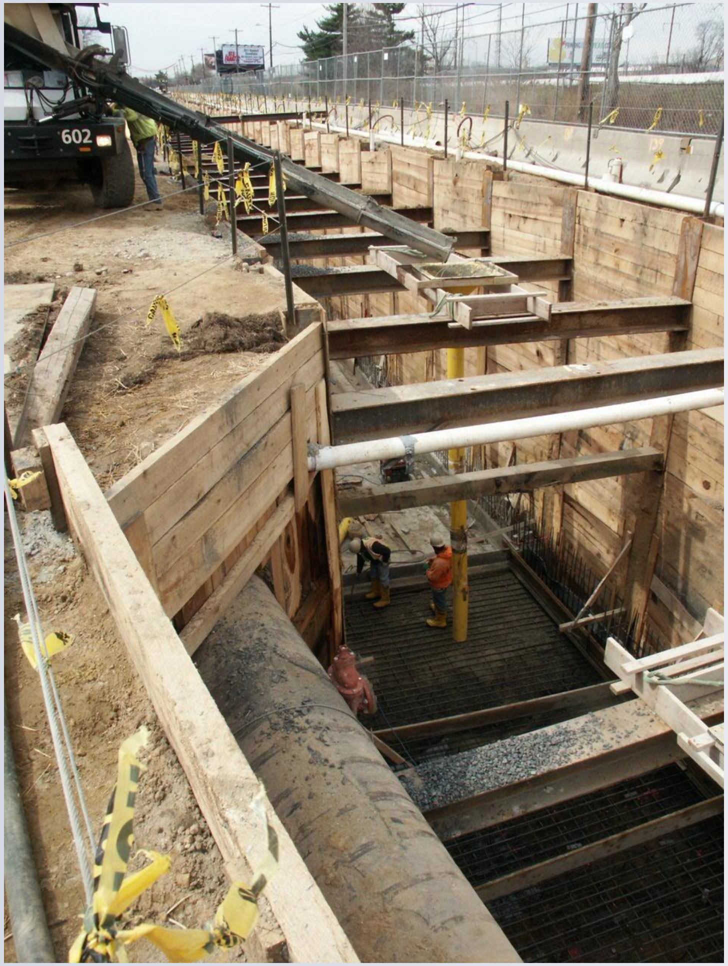
Horizontal Lagging

	Soil Description	Unified Classification	Depth	Recommended Thicknesses of Lagging (roughcut) for Clear Spans of: 5'	6'	7'	8'	9'	10'
COMPETENT SOILS	Silts or fine sand and silt above water table	ML SM-ML							
	Sands and gravels (medium dense to dense).	GW, GP, GM, GC, SW, SP, SM	0' to 25'	2"	3"	3"	3"	4"	4"
	Clays (stiff to very stiff); non-fissured.	CL, CH	25' to 60'	3"	3"	3"	4"	4"	5"
	Clays, medium consistency and $\frac{\gamma H}{S_u} < 5$.	CL, CH							
DIFFICULT SOILS	Sands and silty sands, (loose).	SW, SP, SM							
	Clayey sands (medium dense to dense) below water table.	SC	0' to 25'	3"	3"	3"	4"	4"	5"
	Clays, heavily over-consolidated fissured.	CL, CH	25' to 60'	3"	3"	4"	4"	5"	5"
	Cohesionless silt or fine sand and silt below water table.	ML; SM-ML							
* POTENTIALLY DANGEROUS SOILS	Soft clays $\frac{\gamma H}{S_u} > 5$.	CL, CH	0' to 15'	3"	3"	4"	5"	--	--
	Slightly plastic silts below water table.	ML	15' to 25'	3"	4"	5"	6"	--	--
	Clayey sands (loose), below water table.	SC	25' to 35'	4"	5"	6"	--	--	--

Note:

* In the category of "potentially dangerous soils", use of lagging is questionable.

Soldier Pile Walls with Horizontal Lagging



Soldier Pile Walls with Horizontal Lagging

- Advantages
  - Cost
  - Ease of installation, drive or drill
  - Layout flexibility
- Disadvantages
  - Groundwater control
  - Lagging is difficult in very loose or soft soils

Micropile Walls (Drilled-in Pipe Piles)

- Small diameter (4″ to 12″ dia.), reinforced elements capable of axial and lateral loading
- Micropiles can be used in lieu of HP or WF soldier beams
- Top down construction
- Horizontal lagging between piles

Micropile Walls

Micropile Walls

- Advantages
  - Can be installed in almost any subsurface condition
  - Can be installed vertical or at any angle from horizontal
  - Low vibration drilling techniques suited for sensitive sites
  - Relatively small, light weight equipment
- Disadvantages
  - Higher costs relative to conventional ESS
  - Specialized design procedures are required
  - More difficult to attach lagging and tieback anchors or braces
  - Strength reduction due to pipe joints

Secant Pile Walls

- Drill and concrete piles in primary and secondary sequence
- Pile diameters range from 16” to 36” at spacing slightly less than the diameter
- Piles overlap or interlock with adjacent piles
- Reinforced with WF or HP beams

Secant Pile Walls

- Advantages
  - Construction alignment flexibility
  - Increased wall stiffness
  - Capability in difficult ground conditions
  - Capability in tight working conditions
  - Low vibration
- Disadvantages
  - Verticality tolerances
  - Total waterproofing between joints
  - Cost
  - Greater spoil volume

Deep Soil Mixing Walls

- DSM is process whereby in-situ soils are mechanically mixed with cement and/or other cementitious materials to construct panels of overlapping soil-cement columns
- Exhibit higher strength, lower compressibility, and lower permeability

Deep Soil Mixing Walls

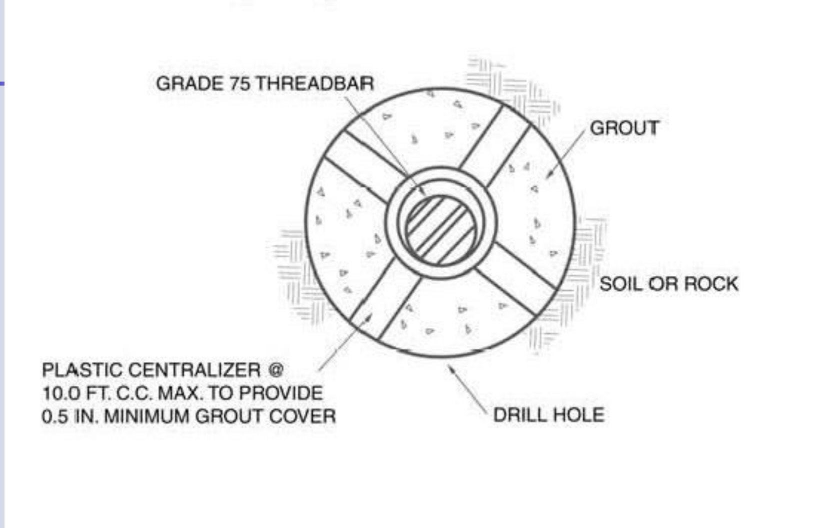
Deep Soil Mixing Walls

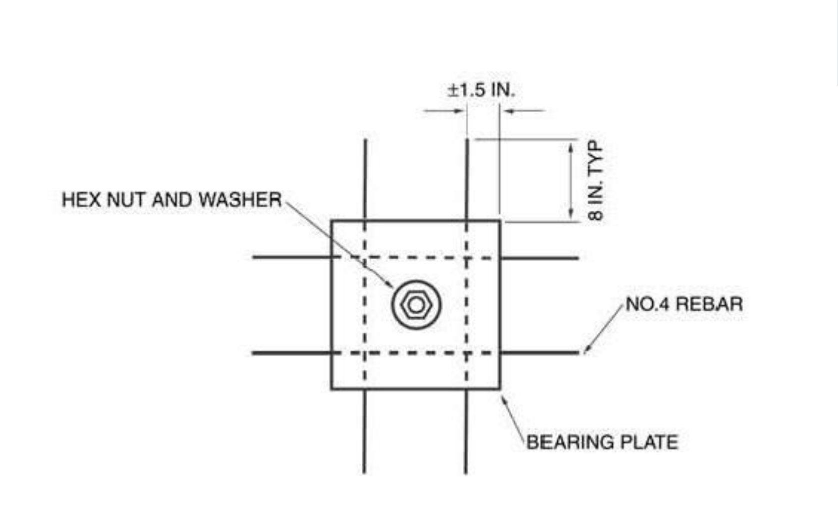
- Advantages
  - Soil is mixed in place, less spoil volume
  - Fast wall construction
  - Limited vibration and low noise
- Disadvantages
  - Difficult in dense soils
  - Uniform mixing often difficult in soft silts or clays often requires re-stoking
  - Large work area with no overhead restrictions required
  - Cost (very expensive mobilization)
  - Large projects only

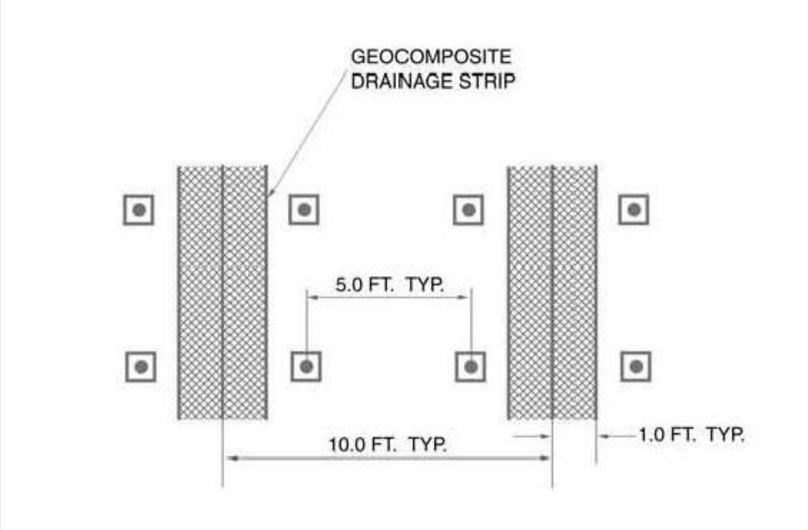
Soil Nail Walls

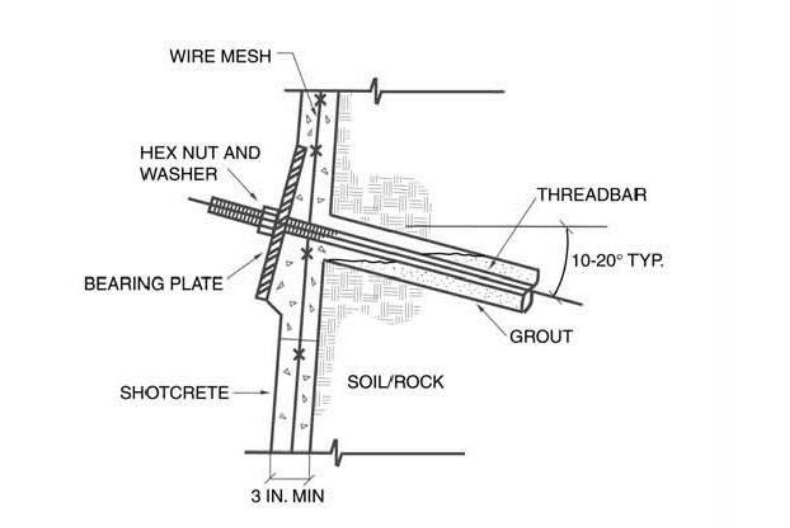
- Increases the overall shear strength of the unsupported soils in-situ through the installation of closely spaced reinforcing bars (nails) into rock/soil
- 4” thick structural concrete facing connects the nails and reduces deterioration and sloughing of excavated face
- Nails become forced into tension when solid deforms laterally as excavation depth increases

Soil Nail Walls









Soil Nail Walls

Soil Nail Walls

Soil Nail Walls

- Advantages
  - Economical, top down construction
  - Effective in glacial till, weathered rock, and residual soils
  - Temporary or permanent applications
- Disadvantages
  - Not recommended for loose soils, expansive clays, and soils lacking cohesion
  - Groundwater presents problems maintaining face stability during lifts
  - Not a replacement for underpinning of buildings

Vertical Wood Sheeting Walls

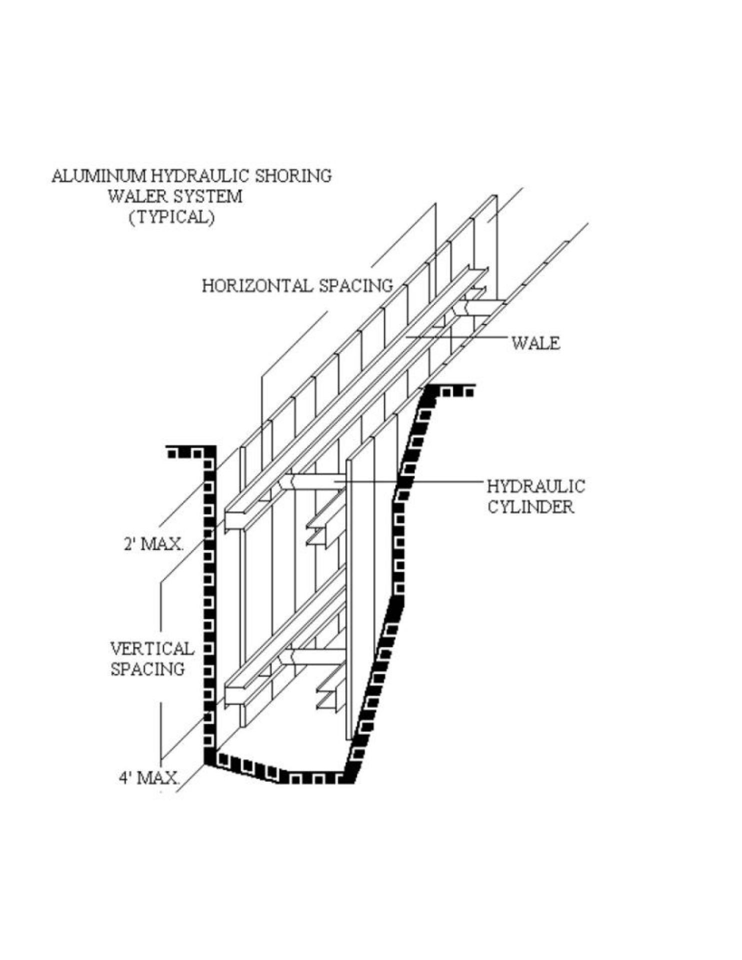
- One of the oldest methods of ground support
- Most common for utility or sewer trenches w/ walls opposite each other to be braced
- 2 to 3 inch nominal thickness, timber planks
- Installed with a light, air-driven hammer or with excavation equipment
- Planks are driven in waves

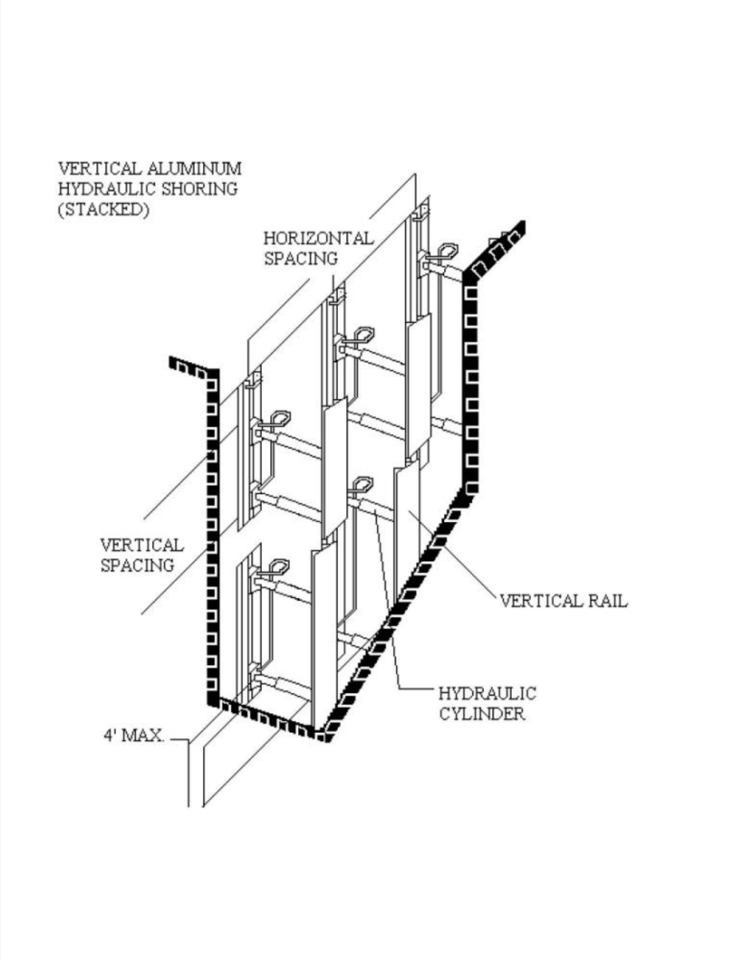
Vertical Wood Sheeting Walls

Vertical Wood Sheeting Walls

- Advantages
  - Small excavations
  - Minimal cost
  - Suitable for use around existing utilities
- Disadvantages
  - Not recommended for wide excavations with multi-level bracing
  - Groundwater
  - Excavation is difficult with multiple brace levels

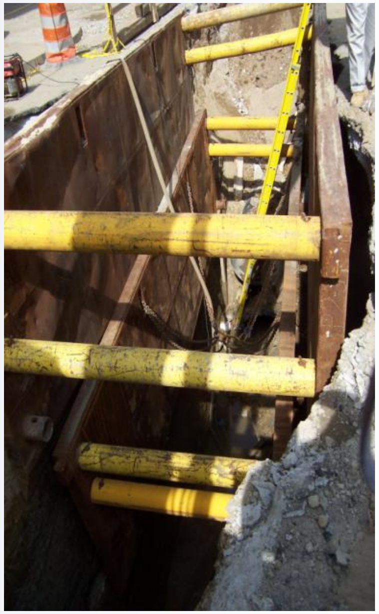
Trench Boxes and Shielding





Trench Boxes and Shielding

- Advantages
  - Moderate depth trenches
  - Manufacturer's supply charts or tables load capacities
- Disadvantages
  - Proprietary systems
  - Installed after trench is excavated
  - Protect workers in trenches, but not adjacent structures or utilities



Diaphragm Walls

- Reinforced concrete wall constructed by excavation utilizing the bentonite slurry method and backfilling with tremie concrete
- True economy of this system is use as permanent structures foundation wall

Diaphragm Walls

Diaphragm Walls

- Advantages
  - Groundwater cutoff
  - Can become a part of the permanent structure
  - Protects adjacent structures
- Disadvantages
  - Very expensive
  - Requires slurry plant
  - Not recommended in soils with large voids or obstructions
  - Cost, very expensive mobilization
  - Limited to large or critical projects

Underpinning

- Introduction of additional support to the foundation to deepen or increase its bearing value
- Most commonly required because of deeper, new construction adjacent to the existing building

Underpinning Sequence

- Preconstruction survey of existing structure
- Install survey monitoring
- Excavate site to within 1' of bottom of existing footing elevation
- Hand excavate and shore approach pit
- Extend and shore approach pit under existing foundation

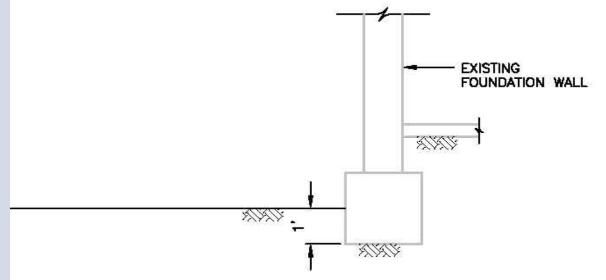


FIGURE 1
NOT TO SCALE

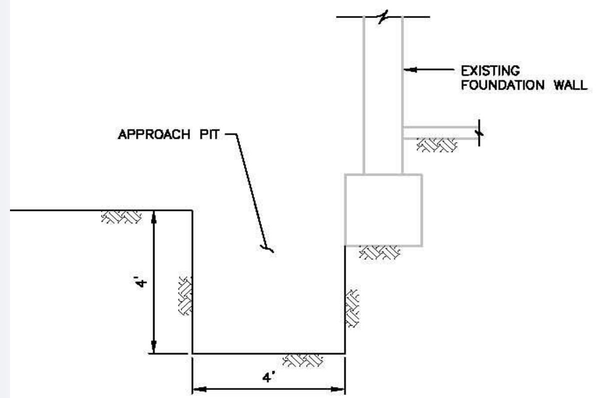


FIGURE 2
NOT TO SCALE

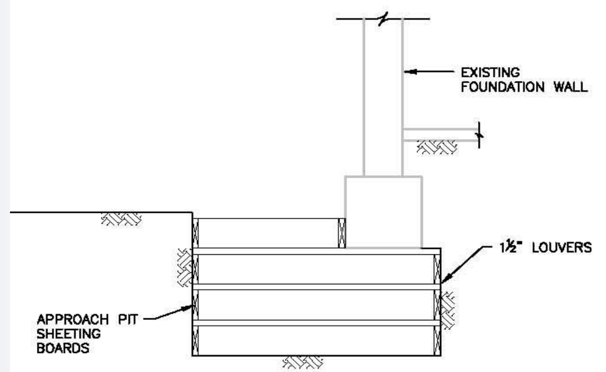


FIGURE 3
NOT TO SCALE

Underpinning Sequence

- Pit shoring
- 2” nominal thickness timber lagging
- Install louvers
- No voids behind pit rings

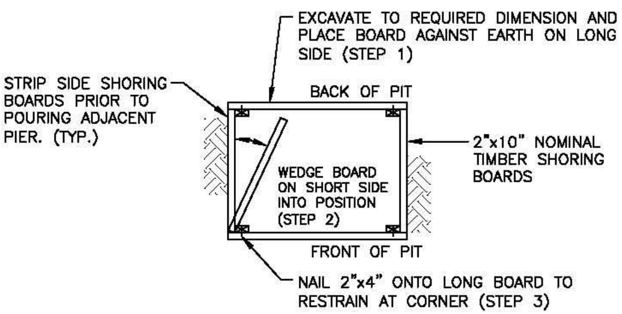


FIGURE 4 – PIT SHORING DETAIL
NOT TO SCALE

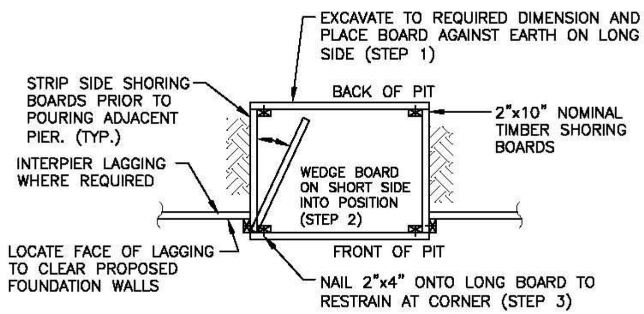


FIGURE 4 – PIT SHORING DETAIL
NOT TO SCALE

Underpinning Sequence

- Excavate by hand and continue shoring in 4' max. lifts to bottom of underpinning pier elevation
- Inspect bottom of pit for adequate bearing capacity
- Bulkhead the approach pit and backfill with concrete
- Free-fall concrete placement
- 2½" space at top for drypack
- Drypack the next day with 2X4 and 8lb. hammer

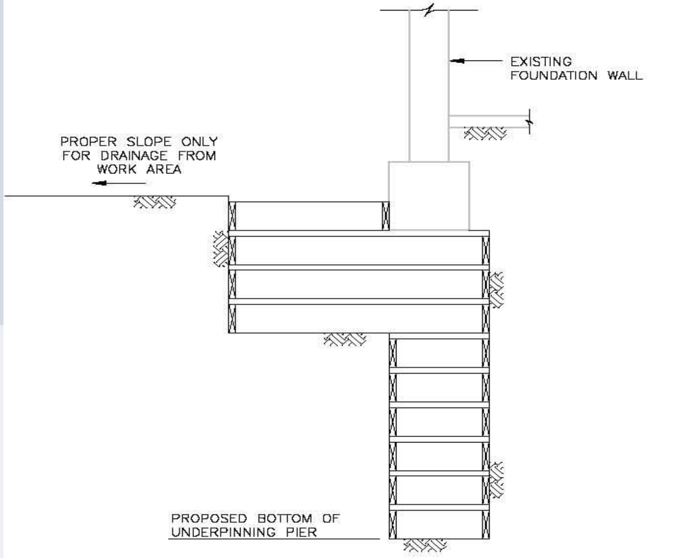


FIGURE 5
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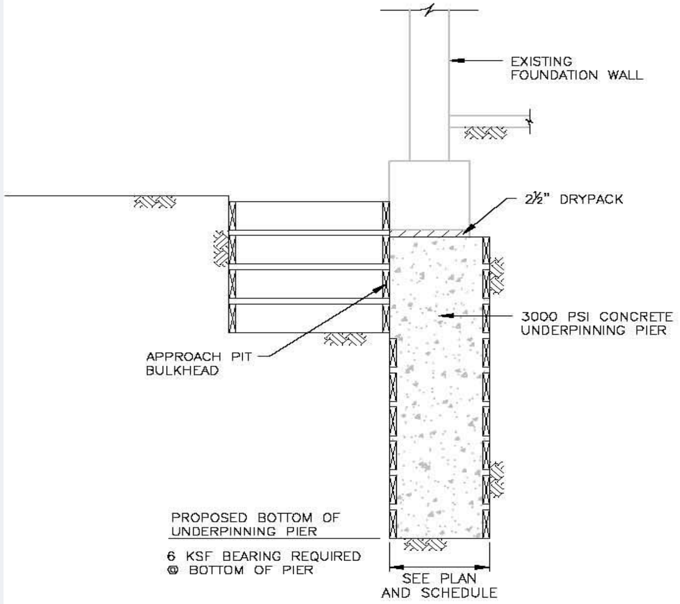


FIGURE 6
NOT TO SCALE

Underpinning Sequence

- No two underpinning pits closer than 12' o.c., nor two adjacent column footings, may be underpinned concurrently!

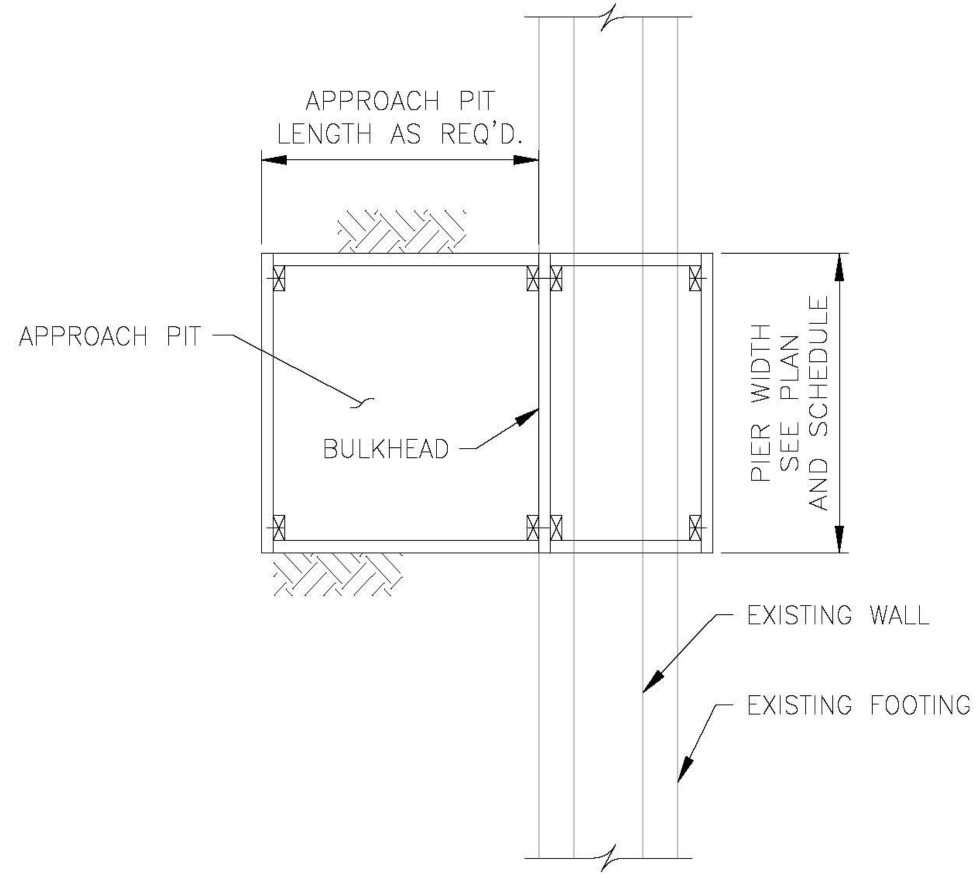


FIGURE 7 – PLAN VIEW
NOT TO SCALE

Underpinning

Underpinning

Underpinning

- Advantages
  - Minimize structure movement
  - Provides both vertical and lateral support
- Disadvantages
  - Costly
  - Hand dug pits
  - Time

Retaining Wall Bracing Systems

- Wales
- Internal Bracing
- Tieback Anchor Systems
  - Tieback Anchor Tendons
  - Tieback Anchor Drilling
  - Grouted Tieback Anchors
- Mechanical Tieback Anchors
- Tiepoint/Thru-tie connections
- Berms

Retaining Wall Bracing Systems

- Provide support for and prevent movement of retaining elements that are in direct contact with the soil

Wales

- In contact with the earth retaining structure
- Transfer loads from retaining structure to the tiebacks or braces
- Allow tiebacks and braces to be spread out, minimize interference with construction operations

Internal Bracing

- HP, WF, HSS (tube) or pipe sections
- Must be designed for combined stress
- Don't forget to consider superimposed loads on braces (excavation material, equipment, materials)

Internal Bracing

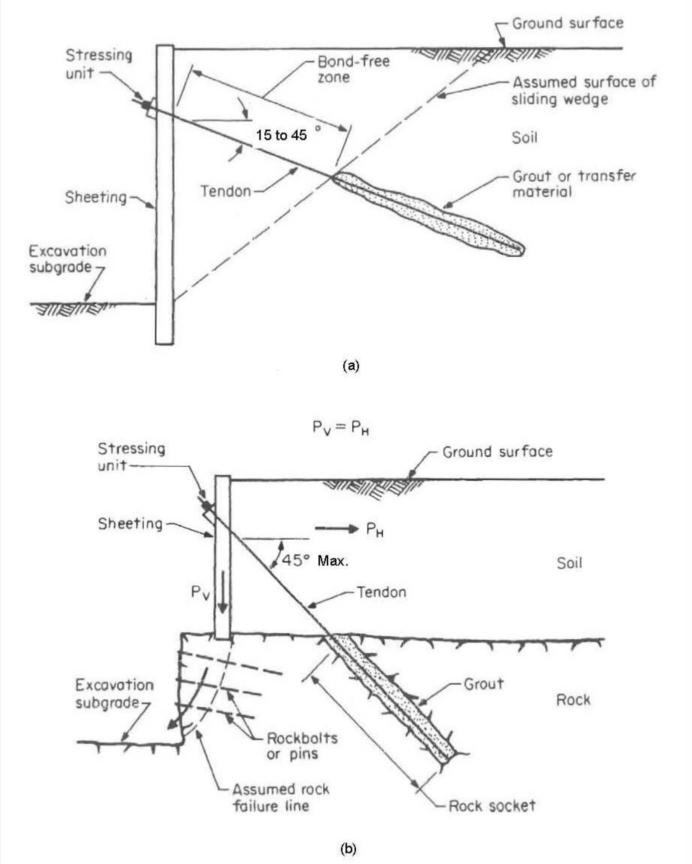
Internal Bracing

Tieback Anchors Systems

- Structural elements which act in tension and receive their support in earth or rock

Tieback Anchors Systems

- Components
  - Tension member (tendon) transfers load
  - Transfer agent (cement grout)
  - Stressing unit (bearing plate & nut or wedges engage tendon)



Tieback Anchor Tendons

- Medium- to high-strength threadbars (75 or 150 ksi) with threaded connections
- Multiple, high-strength strands (270 ksi) with wedge connections
- High-strength bars or tendons maximum working load 60% GUTS
- Low- or medium-strength bars or tendons maximum working load 60% Fy

Tieback Anchor Testing

- All tieback anchors should be tested to between 120% to 133% design load
- Lock-off 75% to 100% design load

Drilling Tieback Anchors

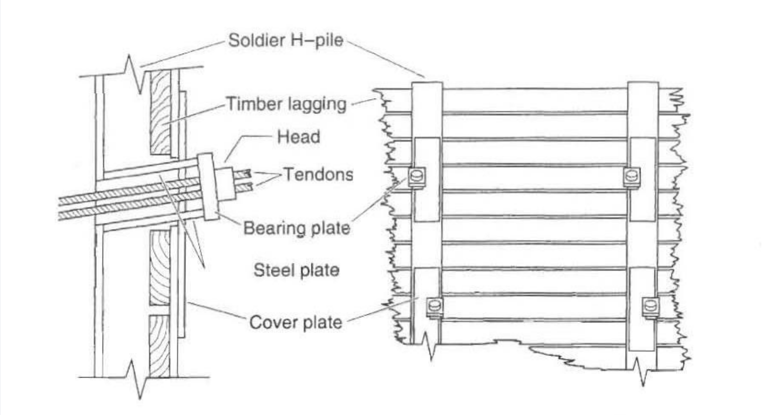
Mechanical Anchors

- Helical or toggle-plate anchors
- Advantages
  - Installed quickly with smaller equipment
  - Can test immediately
- Disadvantages
  - Difficult in rocky or dense soils
  - Low capacity

Tiepoint/Thru-tie Connections

Tiepoint/Thru-tie Connections

- Individual soldier piles are retained by one or more tiebacks without wales
- Advantages
  - Allows smaller clearance between wall and permanent structure
  - Less steel
  - Less excavation
- Disadvantages
  - Possible increase in number of tiebacks



Multiple ESS Working Together

- Often times a project requires multiple ESS systems
- Underpinning with soil nail wall
- Underpinning with soldier beams and timber lagging

Multiple ESS Working Together

- Soldier beams and timber lagging with soil nailing
- Soldier beams and timber lagging with tieback anchors and braced wales

Multiple ESS Working Together

Hot Topics for Discussion

- Contract-specified soil properties
  - Unit weight, Friction angle, Cohesion
- Constructability
- Qualifications
  - Contractor, Designer, Reviewer, Inspector
- Special Inspections

Hot Topic – Soil Properties

- Typical PADOT project specifies "generic" soil values
- Little to no useable testing information provided in geotech reports

Project Specific Details:

The Soil Parameters as indicated in III. (c) 1. are:

1.a Effective angle of friction: 30º
1.b Moist unit weight of soil: 120 pcf
1.c Saturated unit weight of soil: 125 pcf
1.d Effective cohesion: 0 psf
1.e Static groundwater level at elevation: 559.5
1.f Undrained shear strength of cohesive soil: N/A
1.g shear strength of rock mass: 75 psi

Hot Topic – Constructability

- Temporary excavation limits shown on contract drawings
  - Too much; too little
  - Clearance issues
  - Unclosed cofferdams and dewatering
  - NJDOT requires SSP extend 3’ to 4’ above O.G.
- Future ESS problems due to No. 57 crushed stone structural backfill

Hot Topic – Qualifications

- Contractor √
- ESS Designer √
- Reviewer ?
- Inspector ?

V. QUALIFICATIONS - The work must be supervised by a superintendent or foreman who is experienced, in the construction of temporary excavation support and protection system proposed. If the design height of the temporary excavation support and protection system exceeds 6 meters(20 feet), provide the following with the design submission:

- For the superintendent or foreman who will supervise the work, submit a list containing at least 5 projects which demonstrate a minimum of 3 years experience in the construction of the temporary excavation support and protection system proposed. Include a brief description of each project and the name and phone number of the owner's representative knowledgeable in each project listed.

- The name of the Professional Engineer, registered in the Commonwealth of Pennsylvania and having at least 3 years experience in the design and construction of temporary excavation support and protection systems, who will design and specify the sequence of construction of the temporary excavation support and protection of system.

Hot Topic –
Special Inspections




IV. CONSTRUCTION - Install temporary excavation support and protection system in accordance with applicable sections of Publication 408. Be responsible for adequacy, safety and compliance with Traffic Control Plan. If the design is not compliant with the approved Traffic Control Plan, furnish any additional traffic control devices at no additional cost to the Department. All steel and wooden components may remain in place to pavement subgrade or 0.6 meters(2 feet) below finish grade,whichever is higher elevation. Treated wood is not required unless it is within 2 meters(6 feet) of finish grade and is to remain in place. Pressure treat with chromate copper arsenate (CCA) to refusal. Finish grade is defined as top of pavement when a roadway is behind the temporary excavation support and protection system. Have a Professional Engineer, registered in the Commonwealth of Pennsylvania, certify that the temporary excavation support system or open cut excavation has been installed as shown on the Professional Engineer's signed and sealed drawings. Submit the certification to the Representative within 3 working days of completion of the system.

Recommended References

Recommended References

- "Foundation Engineering Handbook" by Winterkorn and Fang
- "Foundation Analysis and Design" by Bowles
- "Recommendations for Prestressed Rock and Soil Anchors" by PTI
- "Geotechnical Engineering Circular No. 4 – Ground Anchors and Anchored Systems" Report No. FHWA-SA-99-015 by FHWA
- "Geotechnical Engineering Circular No. 7 – Soil Nail Walls" Report No. FHWA0-IF-03-017 by FHWA
- "Lateral Support Systems and Underpinning" Report No. FHWA-RD-75-129 and FHWA-RD-75-130 by FHWA
- "Earth Retention Systems Handbook" by Macnab
- "NAVFAC DM-7.1 – Soil Mechanics" by Dept. of the Navy
- "NAVFAC DM-7.2 – Foundations and Earth Structures" by Dept. of the Navy
- "Handbook of Temporary Structures in Construction" by Ratay (3rd Edition Available Spring 2012)

Recommended Websites for Related Geotechnical Publications

- www.fhwa.dot.gov/engineering/geotech/library_listing.cfm
- http://publications.usace.army.mil/publications
- www.PeirceEngineering.com

Thank You!
Any Questions?

Peirce Engineering, Inc.

Civil ~ Construction Engineering

Design of Excavation Support, Ground Anchors, Underpinning, Cofferdams, Micropiles....

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