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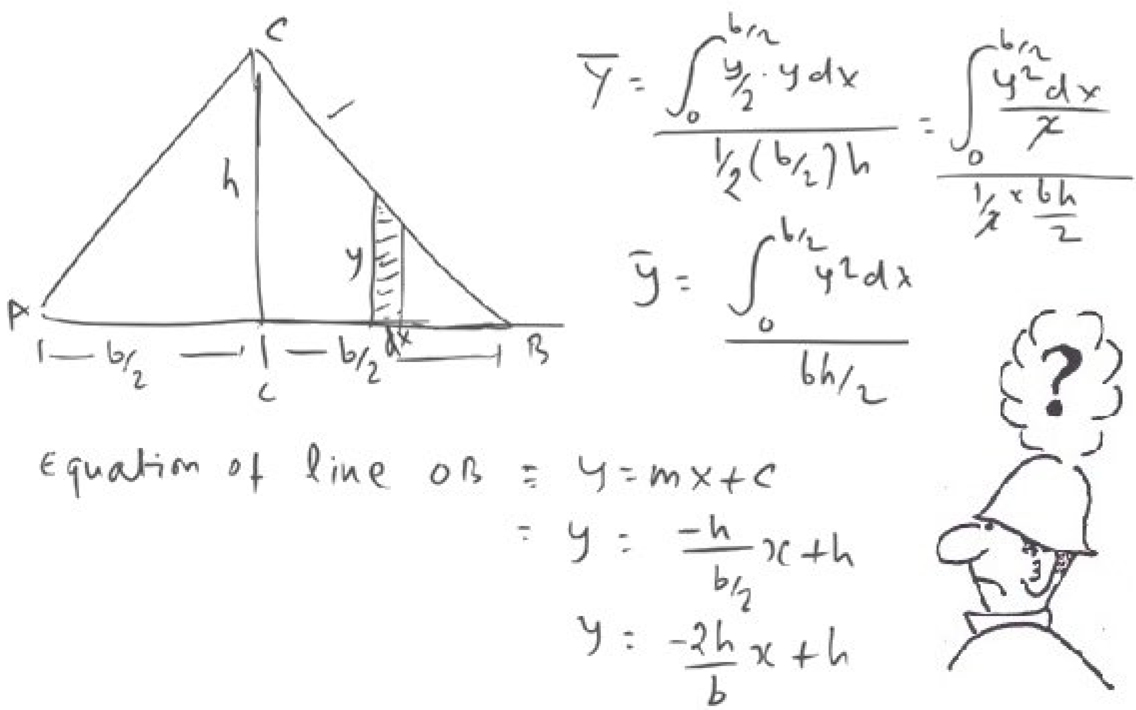
CHAPTER 6

STRUCTURAL DESIGN OF SHORING SYSTEMS



Chapter 6: Structural Design of Shoring Systems

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6-1 Introduction

It is Structure Construction (SC) practice to review the trenching and shoring problems using Allowable Stress Design (ASD), as specified in the *Standard Specifications* for falsework design and the American Railway Engineering and Maintenance-of-Way Association (AREMA) *Manual for Railway Engineering.* The *Guidelines for Temporary Shoring*[1] published by Burlington Northern & Santa Fe Railway (BNSF) and Union Pacific Railroad (UPRR) is more readily available than the AREMA manual (note that Bridge Design has links to various Railroad guidelines in the *Bridge Design Processes and Procedures Manual* (BDPPM[1]) Section 5.1, *Railroad Overview).* This chapter summarizes the allowable values that the reviewer should use for timber and structural steel. For aluminum and concrete members, use the latest acceptable national standard. For timber connections, use the current *National Design Specification for Wood Construction (NDS)* printed by American Wood Council. Historically, these allowable values have provided shoring systems that are rigid and capable to support the earth pressures due to dry and/or saturated soils.

6-2 Allowable Working Stresses

6-2.01 Timber

For timber shoring analysis, reference *Falsework Manual,* Chapter 5, *Analysis*, for guidance on working with allowable working stress values.

Shoring adjacent to railroads is to be designed and reviewed in accordance with railroad requirements. Specific railroad requirements can be found in the railroad's *Guidelines for Temporary Shoring,* which is based primarily on the AREMA manual, Chapter 7, *Timber Structures*, Appendix 4, *Temporary Structures*. Chapter 9, *Railroads*, of this manual presents additional details on shoring systems involving railroads.

Appendix C, *Timber Shoring for Trenches*, of the Cal/OSHA Construction Safety Orders (CSO), § 1541.1, *Requirements for Protective Systems,* defines minimum timber member sizes to use in a shoring system consisting of uprights, walers, and cross bracing members for excavations not exceeding 20 feet in depth and only with the minimum surcharge. Member substitutions for shoring systems to be used in conjunction with the timber tables in Appendix C require they be manufactured members of equivalent strength. Some alternatives to timber shoring are also shown in Appendix E, *Alternatives to Timber Shoring*, of § 1541.1 of the Cal/OSHA CSO. Note that the Construction Safety Orders are found in the California Code of Regulations (CCR) Title 8, Division 1, Chapter 4, Subchapter 4.

[1] Caltrans internal use only

6-2.02 Steel

The maximum allowable stresses are based on the assumed use of structural steel conforming to the American Society for Testing and Materials (ASTM) Grade. Unless otherwise identified, assume the material to be ASTM Grade A36. Since in general, the load carrying capacity of steel beams will be limited by stress, not deflection, the use of higher strength steels may be beneficial. The maximum allowable stress for an identified steel grade must not exceed the limit specified in the current American Institute of Steel Construction (AISC) *Steel Construction Manual*.

When lagging is placed against the front flange of vertical shoring elements, such as wide flange (W) or HP sections, it may be assumed that the entire length of the beam is laterally supported for compression flange buckling (bending) due to the support provided by the lagging. This is the best practice for placement of lagging. If the lagging is placed on the back side of the soldier pile, the soldier pile will need to be checked for compression flange buckling. The allowable bending stress, $\mathbf{F_b}$, could be reduced significantly depending on if the structural section is determined as compact, non-compact, or partially compact as defined in the *AISC Steel Construction Manual*.

For determining allowable stresses for steel members (excluding sheet piles), use the ASD requirements of the AISC *Steel Construction Manual* specifications. Keep the following considerations in mind when analyzing steel components of shoring:

1. Since it is the Contractor's responsibility to design the shoring, there are several standards for the grade of steel the Contractor can choose from to design the sheet piling for temporary shoring. Ensure the check of the Contractor's temporary system adheres to the standards the Contractor is using.
2. For shoring members strictly in compression, determine the allowable axial compressive stress using the AISC *Steel Construction Manual* and assume a steel member with pinned ends.
3. Shoring systems with elements carrying large point loads should be reviewed for web yielding and web crippling. For additional details see Section 5-4.07, *Web Yielding,* and Section 5-4.08, *Web Crippling*, in the SC *Falsework Manual,* and Chapter J, *Design of Connections*, Section J10, *Flanges and Webs with Concentrated Forces,* of the AISC *Steel Construction Manual.*
4. For bolted connections use the most current version of the AISC *Steel Construction Manual*.

For additional details see Section 5-4.14, *Welding Steel Members*, in the SC Falsework Manual for a review of basic information of welded connections.

Railroads have different allowable stress requirements. See Chapter 9, *Railroad,* for information related to the AREMA *Manual for Railway Engineering* requirements and those specific to individual railroad companies.

6-3 Mechanics of Stress Analysis

Use the accepted structural mechanics formulas and theories to perform stress analysis. Review members of the shoring system for flexure, shear, compression, and bearing. Review the shoring system for overall stability; see Chapter 10, *Special Conditions*, of this manual. The *Falsework Manual* provides detailed information on stress analysis for temporary members. This information is applicable for the review of the timber and steel elements of the shoring system. The most relevant and useful sections include the following:

- Chapter 4, *Design Considerations*, Section 4-3, *Beam Continuity*,
- Chapter 5, *Analysis*, Section 5-2, *Timber Members*,
- Chapter 5, *Analysis*, Section 5-3, *Timber Fasteners*, and
- Chapter 5, *Analysis*, Section 5-4, *Steel Members*.

The material to follow is a brief overview, followed by an example checking the lagging for a soldier pile shoring system. See Table 6-1 for some basic structural mechanics formulas related to flexural stress and axial compression.

Table 6-1. Common Structural Mechanics Formulas

Topic	Formula	Variables
Flexural stress (bending)	$\mathbf{f_b = \frac{M}{S} \text{ or } \frac{Mc}{I}}$ (6-3-1)	**M** = Bending Moment **S** = Section Modulus **c** = distance from the neutral axis to extreme fiber **I** = moment of inertia of section about the neutral axis
Axial Compression	$\mathbf{f_c = \frac{P}{A}}$ (6-3-2)	**P** = Applied Load **A** = Area of Member

6-4 Overstress

Short term increases to allowable stresses are allowed (to a maximum of 133 percent) except in the following situations when:

1. Excavations are in place more than 90 days.
2. Dynamic loadings are present (pile driving, traffic, etc.).
3. Excavations are adjacent to railroads.
4. Analyzing horizontal struts.

6-5 Lagging

Lagging is placed between the flanges of either wide flange (W) or HP piles. The practice of installing lagging behind the back flange of the soldier piling is not recommended because the potential arching action of the supported soil will be destroyed. Also, the unsupported length of the compression flange of the beam will be affected. Lagging placed behind the front flange may be wedged back to provide tight soil to lagging contact. Voids behind lagging should be filled with compacted material. Lagging may be installed with a maximum spacing up to 1-1/2 inches between lagging members to permit seepage through the wall system. Movement of soil through the lagging spaces can be prevented by placing or packing straw, hay, or similar material into the spaces. Filter fabric behind the lagging members is usually used for permanent structures.

Construction grade lumber is the most common material used for lagging. Treated lumber is beneficial to use when it is expected that the lagging will remain in place for a long period of time, or permanently. If the use of treated lumber is proposed, check to see that it complies with your contract and permit requirements, especially in and near water sources. Treated lumber is typically Hem-Fir, not Douglas fir, and Hem-Fir has lower reference stress values.

The lagging bridges and retains soil between piles and transfers the lateral soil load to the soldier pile system. Due to the flexibility of the lagging and the soil arching capability, as shown in Figure 6-1, the soil pressure against the lagging may be reduced. For the arching effect to occur, the backside of the soldier pile must bear against the soil.

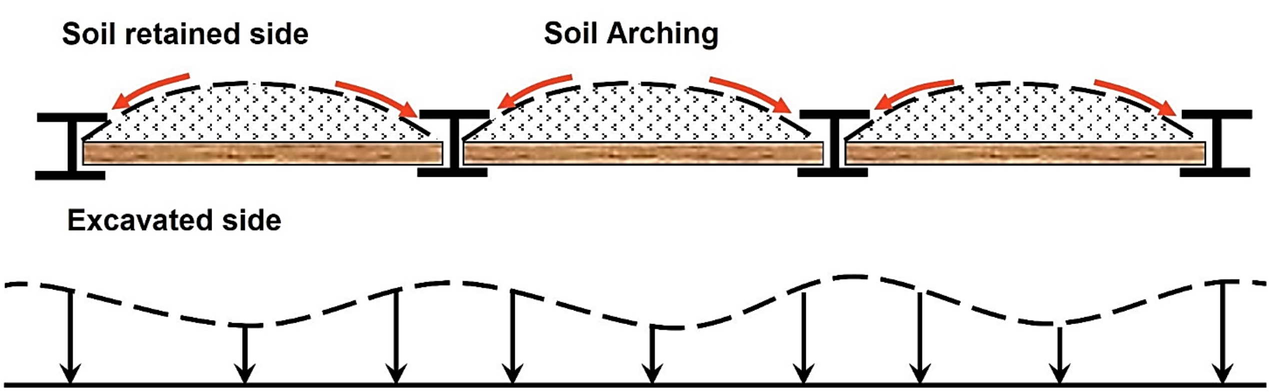

Figure 6-1. Soil Arching

Lateral soil movement within the failure wedge induces soil arching behind the lagging. This soil movement causes the lagging to flex outward. The arching process induces a redistribution of soil pressure away from the center of the lagging toward the much stiffer soldier pile support. Because of this, the design load on the lagging may be taken as 0.6 times the theoretical or calculated earth pressure. Studies have shown that a maximum lagging pressure of 400 psf should be expected when surcharges are not affecting the system. Without soil arching, the pressure redistribution would not occur, and reduced lagging loads should not be considered.

- Lagging design load = 0.6 (shoring design load).
- Maximum lagging load may be 400 psf when no surcharges are present.

The stress analysis of lagging will follow the procedures given in Section 5-2, *Timber Members,* of the *Falsework Manual*.

The Federal Highway Administration (FHWA) published recommended minimum timber thickness for construction grade rough cut Douglas fir. Table 6-2, below, lists lagging recommendations for the following soil classification groupings:

1. Competent Soils: These soils include high internal friction angle sand or granular material or stiff to very stiff clays.
2. Difficult Soils: These soils consist of loose to low internal friction angle cohesionless material, silty sands, and over consolidated clays which may expand laterally, especially in deep excavations.
3. Potentially Dangerous Soils: These soils consist of soft clays, silts below the water table, and clayey sands below the water table. For these soils, the appropriateness of lagging is questionable.

The tabular values may be used for lagging where soil arching behind the lagging can develop. Tabular values should not be used for excavations adjacent to existing facilities, including railroads. Analyze the lagging used in conjunction with surcharges separately.

Table 6-2. FHWA Recommended Minimum Timber Thickness

RECOMMENDED THICKNESS OF ROUGH CUT WOOD LAGGING WHEN SOIL ARCHING WILL BE DEVELOPED* (FOR LOCATIONS WITHOUT SURCHARGE LOADINGS)								
Soil Description	Unified Soil Classification System Group Symbol	Depth	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 $\gamma H/C < 5$.	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 (appropriateness of lagging is questionable)								
Soft clays $\gamma H/C > 5$.	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″			

*Adapted and revised from the April 1976 Federal Highway Administration Report No. FHWA-RD-130.

6-5.01 Example Lagging Calculations

Check the proposed lagging for adequacy.

Given:

- Soldier Pile spacing is 8.5 feet on-center, with a clear-span of 7.5 feet.
- The lagging proposed is 4 x 12 DF #2, (8 feet long members), spaced at 12 inches on center.
- A surcharge is present from an adjacent haul road. The maximum combined soil and surcharge load on the lagging is 580 psf.

Solution:

Step 1: First determine the allowable stresses for shear, bending, and compression perpendicular to the grain per NDS (2018).

Calculate allowable horizontal shear stress:

Reference design value in shear $\mathbf{F_v}$ = 180 psi (NDS Supplement Table 4A)

Applicable adjustment factors from NDS Table 4.3.1:

$\mathbf{C_D}$	= 1.15	Duration Factor (less than two months) NDS Table 2.3.2
$\mathbf{C_M}$	= 0.97	Wet Service Factor NDS Supplement Table 4A (Assume > 19**%** moisture content)
$\mathbf{C_t}$	= 1.0	Temperature Factor NDS Table 2.3.3 (Temp up to 100ºF)
$\mathbf{C_i}$	= 1.0	Incising Factor NDS Table 4.3.8

Adjusted design value:

$$\mathbf{F_v'} = \mathbf{F_v}(\mathbf{C_D})(\mathbf{C_M})(\mathbf{C_t})(\mathbf{C_i}) = \mathbf{201psi} \tag{6-5-1}$$

Calculate allowable compression stress perpendicular to grain:

Reference design value in compression perpendicular to grain, $\mathbf{F_{c\perp}}$ = 625 psi (NDS Supplement Table 4A)

Adjustment factors from NDS Table 4.3.1:

$\mathbf{C_M}$	= 0.67	Wet Service Factor NDS Supplement Table 4A (Assume > 19**%** moisture content)
$\mathbf{C_t}$	= 1.0	Temperature Factor NDS Table 2.3.3 (Temp up to 100ºF)
$\mathbf{C_i}$	= 1.0	Incising Factor NDS Table 4.3.8
$\mathbf{C_b}$	= 1.0	Bearing Area Factor NDS 3.10.4

Adjusted design value:

$$\mathbf{F_{c_\perp}}' = \mathbf{F_{c_\perp}}(\mathbf{C_M})(\mathbf{C_t})(\mathbf{C_i})(\mathbf{C}_{\boldsymbol{b}}) = \mathbf{419\ psi} \tag{6-5-2}$$

Calculate allowable bending stress:

Reference design value in bending F_b = 900 psi for DF #2 (NDS Supplement Table 4A)

Applicable adjustment factors from NDS Table 4.3.1:

C_D	= 1.15	Duration Factor (less than two months; do *not* use Construction load duration for lagging)
C_M	= 1.0	Wet Service Factor NDS Supplement Table 4A (Assume > 19**%** moisture content $(F_b)(C_F) \le 1150$ psi)
C_t	= 1.0	Temperature Factor NDS Table 2.3.3 (Temp up to 100ºF)
C_L	= 1.0	Beam Stability Factor NDS 4.4.1
C_F	= 1.1	Size Factor NDS Supplement Table 4A
C_{fu}	= 1.1	Flat Use Factor NDS Supplement Table 4A (note orientation of lagging)
C_i	= 1.0	Incising Factor NDS Table 4.3.8
C_r	= 1.0	Repetitive Member Factor NDS 4.3.9 (no load distributing element)

Adjusted design value:

$$\mathbf{F_b}' = \mathbf{F_b}\,(\mathbf{C_D})(\mathbf{C_M})(\mathbf{C_L})(\mathbf{C_t})(\mathbf{C_F})(\mathbf{C_i})(\mathbf{C_{fu}})(\mathbf{C_r}) = \mathbf{1252\ psi} \qquad (6\text{-}5\text{-}3)$$

Step 2: Next perform the lagging stress calculations based on the variables below:

A_b	= l_b x w_b	is the Bearing Area at the lagging ends for compression perpendicular to the grain
w_b	=	11.25 inches is the Bearing Width
l_b	=	3 inches is the Bearing Length (lagging centered over clear span)
L_{clr}	=	is the clear span for wood lagging elements
w	=	is the soil pressure on the lagging
V	=	is the shear load

Calculate the uniform load, *w*, on the lagging, including soil and surcharge loads:

$$\mathbf{w} = \mathbf{f} \times \mathbf{W_L} = \mathbf{0.6(580)} \approx \mathbf{348\ psf} \qquad (6\text{-}5\text{-}4)$$

Where 0.6 is the soil lagging arching factor discussed above.

Determine the lagging span length L_{clr}:

Pile spacing is 8.5 feet and the pile width is 12 inches. L_{Clear} = 7.5 feet

Calculate the shear value, V in the lagging:

$$V = \frac{w \times L_{clear}}{2} = \frac{348\ \text{psf}(1\ \text{ft})\ 7.5\ \text{ft}}{2} = 1{,}305\ \text{lbs} \tag{6-5-5}$$

Calculate horizontal shear stress:

V = 1,305 lbs

$$f_v = \frac{3V}{2A} = \frac{3(1305)}{2(3.5)(11.25)} \approx 50\ \text{psi} \tag{6-5-6}$$

50 psi ≤ 201 psi, which is the **F_v'** Allowable calculated above (6-5-1). **<u>OK</u>**

Calculate the compression stress perpendicular to grain:

Use equation to check the bearing (**$f_{c\perp}$**).

$$f_{c\perp} = \frac{V}{l_b \times w_b} \tag{6-5-7}$$

$$f_{c\perp} = \frac{1305\text{lb}}{3\text{in} \times 11.25\text{in}} \approx 39\ \text{psi} \tag{6-5-8}$$

39 psi ≤ 419psi, which is the **$F_{c\perp}$'** Allowable calculated above (6-5-2).

Calculate bending stress:

First determine the actual bearing length, **L**, required by adding the required bearing length to **L_{clr}.**

Rearrange Equation 6-5-7 above and modify to include the allowable compression stress perpendicular to grain, to solve for **l_b**:

$$l_b = \frac{V}{(F_{c_\perp}{'})(w_b)} \tag{6-5-9}$$

$$l_b = \frac{1305}{(419)(11.25)} \approx 0.28\ \text{in} \tag{6-5-10}$$

This is less than the 3 inches assumed, so our assumption was OK.

Thus, the span length is:

$$\mathrm{L} = 7.5' + \frac{0.28}{12} = 7.52\ \mathrm{ft} \tag{6-5-11}$$

Calculate the moment in the lagging (recall it is 1 foot on center), the lagging section modulus, and finally the bending stress within the lagging (note the lagging orientation when calculating the section modulus):

$$\mathrm{M} = \frac{\mathrm{wL}^2}{8} = \frac{(348)(1\ \mathrm{ft})(7.52)^2}{8} = 2460\ \text{ft-lb} \tag{6-5-12}$$

$$\mathrm{S} = \frac{\mathrm{bh}^2}{6} = \frac{(11.25)(3.5)^2}{6} = 23.0\ \mathrm{in}^3 \tag{6-5-13}$$

$$\mathrm{f_b} = \frac{\mathrm{M}}{\mathrm{S}} = \frac{2460(12)}{23.0} \approx 1283\ \mathrm{psi} \tag{6-5-14}$$

1283 psi > 1252 psi, which is the **F_b'** allowable calculated above (Eq. 6-5-3). The lagging fails to meet the bending stress criteria; therefore the Contractor needs to resubmit a new lagging proposal.