CHAPTER 5

STRUCTURAL DESIGN OF SHORING SYSTEMS

5.0 *INTRODUCTION*

It is OSC practice to review the trenching and shoring problems using Allowable Stress Design (ASD) as specified in the Standard Specifications for falsework design, the Construction Safety Orders and the Manual of Railway Engineering (AREMA). 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 National Forest Products Association. Historically, these allowable values have provided shoring systems that are rigid and strong to support the earth pressures due to dry and/or saturated soils.

5.1 *ALLOWABLE WORKING STRESSES*

5.1.1 Timber

The Construction Safety Orders Appendix C to Section 1541.1(See Appendix A) defines minimum timber member sizes to use in a shoring system consisting of uprights, wales, and cross bracing members for excavations up to 20 feet depth. Member substitutions for shoring systems to be used in conjunction with the timber tables of Appendix C to Section 1541.1 require that they be manufactured members of equivalent strength. Some alternate cross bracing manufactured members are shown in Appendix E to Section 1541.1 of the Safety Orders.

For timber shoring analysis you may reference the most recent version of the NDS for Wood Construction Manual to obtain allowable working stresses.

When shoring plans designed by a qualified engineer do not specify stress limitations or list type of lumber (timber), OSC will review the plans assuming Douglas Fir Larch (North) Group II with the following stress limitations:

$F_{c_{\parallel}} = 480{,}000\ (L/D)^2$ psi	Compression Parallel to Grain Not to exceed 1,600 psi
$F_b = 1{,}800$ psi	Flexural (bending) Reduced to 1,500 psi for members with a nominal depth of 8 inches or less.
$F_t = 1{,}200$ psi	Direct Tension

$F_{c\perp}$ = 450 psi	Compression Perpendicular to Grain
V = 140 psi	Horizontal Shear
E = 1.6 x 10^6 psi	Modulus of Elasticity Use 1.2 x 10^6 psi for wet or green-timber

Lesser stress values shown on the shoring plans or in the accompanying calculations will be used for review.

When lumber (timber) type is listed or shown on the shoring plan without allowable stress values the NDS will be used as a guide. If the specific lumber grading is not included, use the lowest allowable NDS stress values.

Railroads allow 1,710 psi maximum in lieu of 1,800 psi for flexural stress for Douglas Fir-Larch, Dense Select Structural timber. Shoring adjacent to railroads is to be designed and reviewed in accordance with railroad requirements. Specific railroad requirements can be found in the AREMA Manual for Railway Engineering, Chapter 7, Section 2.13 Temporary Structures and are included in CHAPTER 8 of this Manual.

5.1.2 Steel

The maximum allowable stresses, generally, are based on the assumed use of structural steel conforming to 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. However, since there are no specifications to cover the design stress criteria, the following information may be used for rolled steel sections or you may refer to current AISC specifications.

If grade of steel is unknown, use A36 (F_y = 36 ksi, E = 30 x 10^6 psi).

For determining allowable shear stress the following equation is used:

$$F_v = 0.4\,F_y \qquad \text{Eq. 5-1}$$

For determining allowable bending stresses for steel members, (excluding sheet piles) the AISC requirements for ASD are used. For vertical shoring elements such as W or HP sections, it is assumed that the entire length of the beam is laterally supported due to the lagging. Therefore, determining the allowable bending stress, F_b, is based on this assumption. The allowable bending stresses for rolled steel sections are based on how the member is classified; as a compact, non-compact, or partially compact section based on the following criteria:

For Compact Sections the following criteria must be met:

$$\frac{b_f}{2t_f} \leq \frac{65}{\sqrt{F_y}} \text{ and } \frac{h}{t_w} \leq \frac{640}{\sqrt{F_y}}$$

For Non compact Sections the following criteria must be met:

$$\frac{65}{\sqrt{F_y}} < \frac{b_f}{2t_f} \leq \frac{95}{\sqrt{F_y}} \text{ and } \frac{640}{\sqrt{F_y}} < \frac{h}{t_w} \leq \frac{970}{\sqrt{F_y}}$$

Therefore, the allowable bending stress, F_b, is determined as the following:

Table 5-1. Laterally Supported Beams

Non Compact Flange $\frac{65}{\sqrt{F_y}} < \frac{b_f}{2t_f} \leq \frac{95}{\sqrt{F_y}}$ Non Compact Web $\frac{640}{\sqrt{F_y}} < \frac{h}{t_w} \leq \frac{970}{\sqrt{F_y}}$	Non Compact Section	$F_b = 0.6\,F_y$
Non Compact Flange $\frac{65}{\sqrt{F_y}} < \frac{b_f}{2t_f} \leq \frac{95}{\sqrt{F_y}}$ Compact Web $\frac{h}{t_w} \leq \frac{640}{\sqrt{F_y}}$	Partially Compact Section	$F_b = F_y * \left[0.79 - 0.002 * \frac{b_f}{2 * t_f} * \sqrt{F_y}\right] \leq 0.66 * F_y$
Compact Flange $\frac{b_f}{2t_f} \leq \frac{65}{\sqrt{F_y}}$ Compact Web $\frac{h}{t_w} \leq \frac{640}{\sqrt{F_y}}$	Compact Section	$F_b = 0.66\,F_y$
Compact Flange $\frac{b_f}{2t_f} \leq \frac{65}{\sqrt{F_y}}$ Non compact Web $\frac{640}{\sqrt{F_y}} < \frac{h}{t_w} \leq \frac{970}{\sqrt{F_y}}$	Non compact Section	$F_b = 0.6\,F_y$

Please refer to AISC for beam conditions where the compression flange is not fully supported.

For determining critical flange buckling stress, the following formula may be used:

$$f\ (\text{maximum}) = \frac{12{,}000{,}000}{\frac{Ld}{bt}}$$

Where:

L = unsupported length.

d = depth of the member

bt = area of the compression flange.

The above value is limited to no more than 22,000 psi for unidentified steel. For identified steel the above value should be limited to the criteria for compact and non-compact sections as discussed above.

Steel sheet piling: use Grade A328 steel for which F_b = 25 ksi, unless specific information is furnished for a higher grade steel.

For determining the allowable axial compressive stress on a steel member with pinned ends, the following formula may be used for A36 steel only:

$$\frac{P}{A} = 16{,}000 - 0.38\left(\frac{L}{r}\right)^2$$

For A50 grade steel:

$$\frac{P}{A} = 22{,}000 - 0.74\left(\frac{L}{r}\right)^2$$

r = least radius of gyration of the section
L = unsupported length
L/r maximum is limited to 120

For web crippling, the allowable stress is 27,000 psi.

For the analysis of bi-axial bending, OSC best practice requires investigation when the cross slope or cant of a beam is greater than 2%. For additional details see the OSC Falsework Manual.

For bolted connections use the most current version of the AISC Manual.

The strength of fillet welded connections may be approximated by assuming a value of 1,000 lbs per inch for each 1/8 inch of fillet weld.

Railroads have different allowable stress requirements. See CHAPTER 8 Railroad of this Manual. (Section 8.1.5.7 Structural Integrity.)

5.2 *MECHANICS OF STRESS ANALYSIS*

Use the accepted structural mechanics formulas and theories. Check member of the shoring system for flexure, shear, compression, and bearing. Check the system (with soil) for stability. Approximate calculations are satisfactory for most shoring systems.

Common structural mechanics formulas:

Flexural stress (bending)

$$f_b = \frac{M}{S} \text{ or } \frac{Mc}{I}$$

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

$$f_C = \frac{P}{A}$$

P = Applied Load
A = Area of Member

Timber

Compression ⊥ grain

$$f_\perp = \frac{P}{A}$$

Horizontal Shear

$$f_v = \frac{(1.5)(w)\left(\frac{L}{2} - \frac{b}{2} - d\right)}{A}$$

L = span length (center to center)
b = thickness of supporting member or length of bearing stress area, whichever is less
d = depth of member for which shear is being investigated
w = unit load

Steel

Shear

$$v = \frac{V}{(h * t_w)}$$

V = is the vertical shear
h = overall depth of the beam (out to out of the beam flanges).
t_W = the thickness of the beam web

Web Crippling*

For end reactions

$$f = \frac{R}{(a + k)(t_w)}$$

For interior reactions

$$f = \frac{R}{(a + 2k)(t_w)}$$

* AISC 9th Edition redefines this as Web Yielding

R = concentrated load or end reaction
a = length of bearing
k = distance from the outer face to the flange to the web toe of fillet.

All dimensions are in inches.

For lagging, use simple span moments. Multiply all loads by 0.6 to account for soil arching.

$$M = (0.6)\frac{wL^2}{8}$$

In many cases the effective span for lagging will be less than the spacing of the supports.

For additional information on lagging see section 5.4 LAGGING in this chapter.

For interior moments of uniformly loaded continuous uprights, walers, or rails, then the following formula may be used:

$$M = \frac{wL^2}{10}$$

For cantilevers use:

$$M = \frac{wL^2}{2}$$

The Design Earth Pressure Diagram will be the sum of the basic earth pressure, surcharge loads, and any other applicable loads (such as ground water).

Since calculating earth pressures is not precise, an irregular-shaped composite diagram may be simplified by using standard geometrical shapes (rectangles, triangles, etc.).

5.3 *OVERSTRESS*

Short term increases to allowable stresses are allowed (to a maximum of 133%) 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.

5.4 *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 1½ 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.

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 5-1, multiplying the maximum earth pressure by a reduction factor of 0.6 reduces the soil pressure distribution behind the lagging.

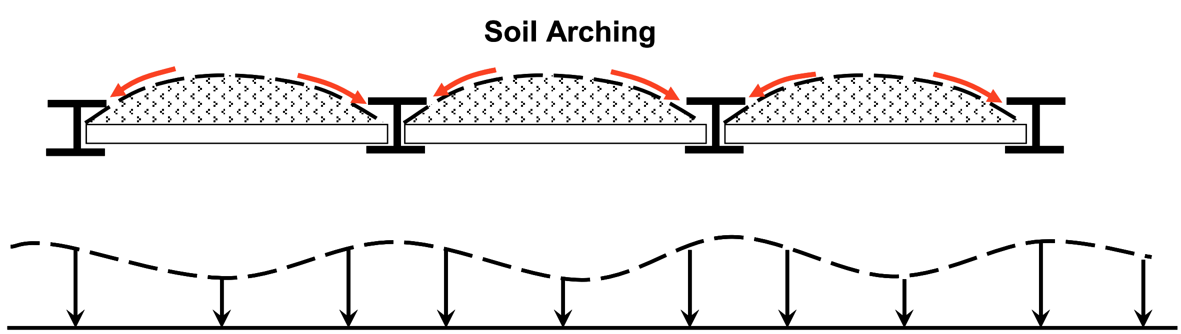

Figure 5-1. Soil Arching

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.

Lateral soil movement within the failure wedge induces soil arching behind 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. For the arching effect to occur the backside of the soldier pile must bear against the soil.

- Lagging design load = 0.6 (shoring design load).
- Maximum lagging load may be 400 psf without surcharges.

Table 5-2 lists FHWA recommended minimum timber thickness for construction grade Douglas Fir lagging for the following soil classifications.

- Competent Soils: These soils include high internal friction angle sand or granular material or stiff to very stiff clays.
- 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.
- Potentially Dangerous Soils: The use of lagging with potentially dangerous soils 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. Lagging used in conjunction with surcharges should be analyzed separately.

Table 5-2. FHWA Recommended Minimum Timber Thickness

RECOMMENDED THICKNESS OF WOOD LAGGING WHEN SOIL ARCHING WILL BE DEVELOPED* (FOR LOCATIONS WITHOUT SURCHARGE LOADINGS)								
Soil Description Classification	Unified	Depth	Recommended Thickness of Lagging (rough cut) 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 γH/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 γH/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.								