Shoring

- In multistory work, the shoring which supports freshly placed concrete is necessarily supported by lower floors which
  - may not yet have attained their full strength,
  - and which may not have been designed to carry loads as great as those imposed during construction
- Construction loads may exceed design loads by an appreciable amount.

(Ref: Grundy & Kabaila, ACI J., Dec. 63, pp. 1729-1738)
Shoring

Therefore shoring must be provided for enough floors to develop the needed capacity to support the imposed loads without excessive stress or deflection.

Whether permanent shores or re-shores are used at the several required lower floor levels depends on job plans for reused of materials as well as the rate of strength gain in the structure.

Shoring

There are several types of adjustable individual shores.

The simplest of these, is based on clamping device which permits the overlapping of two 2x4 members.
Temporary Structures

Shoring

- A portable jacking tool is used to make vertical adjustments.
- Metal shore jack fittings are available to fit over the end of 4x4 or 6x6 wood shore, thus transforming the piece of lumber into an adjustable shore.
- These devices are capable of varying the shore height as much as 12 in.

- A number of patented shoring systems have been developed with adjustable legs which eliminate cutting, close fitting, and wedging.
Scaffold-Type Shoring

- When tubular steel frame scaffolding was first introduced, it was designed to support the relatively light loads involved in getting workers to the work area.
- Later contractors began to try out the scaffolding as a support for formwork because of the apparent advantages of its modular assembly and system of jacks for leveling and adjusting elevations.

Scaffold-Type Shoring

- End frames assembled with diagonal braces to form typical shoring “tower”.

[Diagram showing scaffold-type shoring with end frames, adjustable jacks, and cross braces.]

Professor Kamran M. Nemati
Spring Quarter 2018
Scaffolding

- Scaffolding has been used for 5000 years to provide access areas for building and decorating structures taller than people who work on them.

Walk-through-type frames used by masons

- The word “scaffolding” refers to any raised platform or ramp used for ingress and egress for pedestrian movement and/or the passage of building materials.

- Since the mid-1920s the concept of using steel pipes fastened together with metal-form or cast clamps (couplers) instead of poles and ropes was introduced.
Scaffolding

- Aluminum alloy pipes and couplers were developed for their lighter weight and speedier construction.
- Aluminum alloy is only two-thirds as strong as steel, but it is only one-third to one-half its weight.
- Because of the higher initial cost, aluminum is restricted mostly to building maintenance scaffolds and suspended platforms.

Scaffolding General Design Considerations

- Commonly, all types of scaffold have incorporated in their design a minimum safety factor of 4.
- This means that scaffolds and their components shall be capable of supporting without failure at least 4 times the maximum intended load.
- To comply with this requirement, multiply the design load by 4 and derive the limiting strength of the component from the yield stress of the metal in accordance with acceptable engineering criteria and practices.
Scaffolding - Design Loads

- In accordance with OSHA and ANSI criteria and common practice for many years, design load ratings for scaffold platforms are as follows:
  - **Light-Duty Loading.** 25 lb/ft$^2$ maximum working load for support of people and tools (no equipment or material storage on the platform).
  - **Medium-Duty Loading.** 50 lb/ft$^2$ maximum working load for people and material restricted not to exceed this rating, often described as applying to bricklayers’ and plasters’ work.
  - **Heavy-Duty Loading.** 75 lb/ft$^2$ maximum working load for people and stored material often described as applying to stone masonry work.

These ratings assume uniform load distribution.

With the exception of the weight of stored materials, scaffold loads most often consist of personnel, both stationary and transitory.

It is important to remember that the OSHA and ANSI load-rating system is intended for guidance of field personnel in the construction and use of nonspecifically engineered scaffolding applications.
Temporary Structures

Shoring and Scaffolding

Tube and Coupler Scaffolds

- Tube and coupler scaffolds are assembled from three basic structural elements:
  - The uprights, or posts, which rise from ground or other solid support
  - The bearer, which supports the work platforms and / or provide transverse horizontal connections between the posts;
  - The runners, which attach to the posts directly below the bearers and provide longitudinal connections along the length of the scaffold.

These three elements are usually connected with standard or fixed couplers which provide a 90° connection in two places.

The three elements (uprights, bearer, and runners) form the basic structure.
Tube and Coupler Scaffolds

- The basic assembly and components of tube and coupler scaffolds.

- Diagonal bracing is used to stiffen the structure as necessary – most important in the longitudinal direction.

- Bracing is generally connected to the posts with “adjustable” or “swivel” couplers which have the facility of adjusting a full 360°.

- Diagonal bracing should always be attached to the posts as closely as practical to the “node” points formed by the runner-bearer connections.
Temporary Structures

Tube and Coupler Scaffolds

- Another important structural element is the building tie which connects the scaffold to the wall or structure and is needed to provide rigidity and anchorage of the scaffold in the transverse direction.
- Scaffolds need to be laterally supported; otherwise, they are unstable because of their height-to-width ratio and have low strength to resist wind and other lateral forces.

Tube and Coupler Scaffolds

Methods of stabilizing against a building

a) Wall tie and anchorage
Tube and Coupler Scaffolds

- Methods of stabilizing against a building (cont'd):
  
  b) Window reveal tube

![Diagram of window reveal tube]

- Methods of stabilizing against a building (cont'd):
  
  c) Reveal between pilasters

![Diagram of reveal between pilasters]
Tube and Coupler Scaffolds - Application

- Tube and coupler scaffolds can be assembled in numerous ways because of the flexibility of their assembly dimensions in the horizontal and vertical planes.
- Unlike sectional frame scaffolds they are not restricted by frame width in the transverse direction, by brace length in the longitudinal direction, or by frame height in the vertical direction.
- Consequently, they are preferred for access to workplaces having irregular dimensions and contours, e.g., churches, old auditoriums, etc.

Tube and Coupler Scaffolds

Basic Configurations

- The basic configurations are as follows:
  1. Double Pole. Also called “independent” wall scaffolds, these are used for access to vertical surfaces for construction, alterations, or surface finishing and repair. They consist of repetitive pairs of posts along the length, connected by bearers and runners.
  2. Single pole. Also called “putlog” wall scaffolds, these are used for the construction of masonry walls. They consist of single posts 3 to 5 feet away from the wall surface spaced at regular or varying intervals along the wall. The different feature of this type of scaffold is that the inside ends of the bearer are supported at joints or courses in the wall being built instead of the inside posts.
Tube and Coupler Scaffolding

**BASIC CONFIGURATIONS**

3. **Tower Scaffolds.** These consist of one or few bays in either horizontal plane, constructed to required height for access to ceilings or for specialized load support requirements not conveniently achievable with sectional frames. They may be mounted on casters and become mobile scaffolds or rolling towers.

- An application of tower scaffolds is to provide stair access to unusual structures such as cooling towers.

Sectional Scaffolding

- The construction principle of sectional scaffolding is shown below.
Sectional Scaffolding

- The most common material used in the fabrication of steel frames is 1 5/8-in.–OD tubing with a wall thickness between 0.086 and 0.105 in.
- The most common grade of steel used for this purpose is AISI designation A1050, a high-carbon alloy having a minimum yield stress of 50,000 psi with a corresponding ultimate stress of over 75,000 psi.
- The higher carbon steel is generally preferred because its lower ductility and greater rigidity make it more resistant to damaging and bending of the members and because it has greater strength.

Example

- A sectional steel frame scaffolding system will be used during the construction of a stone masonry building facade. The lower, middle, and upper working levels of the scaffolding are 15 ft., 20 ft., and 25 ft. above grade, respectively. The frames are 5 feet wide.
  a) Considering only dead load and live load, what is the maximum leg load on the scaffolding if the frames are located 6 feet apart?
  b) 4” x 4” x 1/2” thick steel plates at the bottom of the scaffolding sit on 2x12 wood planks (Douglas fir-larch, construction grade). Can the planking support the bearing stress induced by the maximum leg load calculated in part a. above?
Example

Part a)
- Total load = 6’ x 5’ x 75 psf = 2,250 lbs split evenly between two legs
- Maximum leg load = 2,250/2 legs = 1,125 lbs

Part b)
- F.S. = 4
- load = 1125 lb x 4 = 4,500 lbs
- From Table 4-2, Fc⊥ = 625 psi
- Bearing Area (steel plate) = 4” x 4” = 16 in.²

\[
\frac{\text{Load}}{\text{Area}} = \frac{4,500 \text{ lbs}}{16 \text{ in}^2} = 281.25 \text{ psi} < 625 \text{ psi} \Rightarrow \text{OK}
\]
Temporary Structures
Shoring and Scaffolding

Shoring in Existing Buildings

[Image of shoring in an existing building]

Shoring in Existing Buildings

[Image of shoring in an existing building]
Shoring in Existing Buildings

Shoring in Existing Buildings
Shoring in Existing Buildings

Shoring in Existing Buildings
**Simple Wood Shores**

- Common wood shores, either rectangular or round in cross sections, are designed as simple solid columns. As in the design of columns of all types, the load capacity depends on the slenderness ratio.

**Slenderness Ratio**

- The Slenderness Ratio is the relationship of unsupported length of shore to the cross-sectional dimension in the face under consideration.
- If the shore is unbraced, use the dimension of the narrow face in determining the ratio

\[ l_e = \frac{kL}{r} \]

- \( l_e \): Effective length
- \( k \): End Condition
- \( L \): Unsupported Length
- \( r \): Radius of gyration
Slenderness Ratio

- When shores are braced laterally on one or more faces, or at different points along their length, the slenderness ratio in each plane of lateral support must be determined. The greatest value should be used for computing allowable loads.
- Example: Determine the largest slenderness ratios for the following cases. Use a 3 x 4 post.

\[
\frac{L}{d}1 = \frac{(15 \times 12)}{3.5} = 51.4 \\
\frac{L}{d}2 = 180^\circ / 2.5 = 72 \text{ (max)}
\]

Use \( L/d = 72 \)

\[
\frac{L}{d}1 = \frac{(15 \times 12)}{3.5} = 51.4 \text{ (max).} \\
\frac{L}{d}2 = 90^\circ / 2.5 = 36
\]

Use \( L/d = 51.4 \approx 52 \)

---

Slenderness Ratio

\[
\frac{L}{d}1 = \frac{(7.5 \times 12)}{3.5} = 25.6 \approx 26 \text{ (max.)}
\]

\[
\frac{L}{d}2 = \frac{(5 \times 12)}{2.5} = 24
\]

Use \( L/d = 26 \)
Adjustment Factor for Solid Wood Columns

- The base compression stresses, like other stresses must be adjusted for temperature, size, load duration, and moisture, as well as STABILITY FACTOR $C_P$.

- Since wood shores are generally used repeatedly, ACI Code (Committee 374) does not recommend routine application of any adjustment that provides increased stresses for short load duration.

Column Stability Factor $C_P$

- The following simplified formula for $C_P$ has been suggested for graded sawn lumbers:

$$ C_P = \frac{1 + x}{1.6} - \sqrt{\frac{1 + x}{1.6}} - \frac{x}{0.8} $$

$$ x = \frac{0.3 E'}{\left(\frac{l}{d}\right)^2} \times \frac{1}{F'_C} $$

$$ F'_C = C_P \times F_C^* $$

- $E'$: Adjusted Modulus of Elasticity,
- $F_C^*$: Adjusted stress in compression parallel to grain
- $l/d$: Slenderness ratio $\leq 50$ (Code Requirement)
- $F'_C$: Allowable Compression Stress
Example: Allowable load on 4x4 wood shore

What load will a 4x4 S4S No. 2 grade Douglas Fir-Larch shore carry if its effective (unsupported) length is 9 feet?

Solution:

From Table 4-2:  
\[ F_C = 1350 \text{ psi (base value)} \]
\[ E = 1,600,000 \text{ psi} \]

From Table 4-2B:  
Size Adjustment = 1.15
No adjustment for \( E \)

Adjusted Values:

\[ F_C^* = 1.15 \times 1350 = 1552 \text{ psi} \]
\[ E = 1,600,000 \text{ psi (no adjustment)} \]

\[ x = \frac{0.3E'}{\left(\frac{l}{d}\right)^2} \times \frac{1}{F_C^*} \]
Example: Allowable load on 4x4 wood shore (cont'd)

\[ l/d = (9 \times 12) \div 3.5 = 30.9 \]

\[ x = \frac{0.3 \times 1,600,000}{[30.9]^2} \times \frac{1}{1,552} = 0.324 \]

\[ C_p = \frac{1 + x}{1.6} - \sqrt{\left[ 1 + \frac{x}{1.6} \right]^2 - \frac{x}{0.8}} \]

\[ C_p = \frac{1 + 0.324}{1.6} - \sqrt{\left[ 1 + \frac{0.324}{1.6} \right]^2 - \frac{0.324}{0.8}} \]

\[ C_p = 0.828 - \sqrt{0.685 - 0.405} = 0.828 - 0.529 = 0.299 \]

\[ F'_c \text{ (allowable stress)} = C_p \cdot F'_c = 0.299 \times 1,552 = 464 \text{ psi} \]

\[ P_c = F'_c \times A = 464 \text{ psi} \times 12.25 \text{ in}^2 = 5,684 \text{ lb} \]

Example: Allowable load on 4x4 wood shore (cont'd)

\[ l/d = (4.5 \times 12) \div 3.5 \approx 15.5 \]

\[ x = \frac{0.3 \times 1,600,000}{[15.5]^2} \times \frac{1}{1,552} = 1.287 \]

\[ C_p = \frac{1 + x}{1.6} - \sqrt{\left[ 1 + \frac{x}{1.6} \right]^2 - \frac{x}{0.8}} \]

\[ C_p = \frac{1 + 1.287}{1.6} - \sqrt{\left[ 1 + \frac{1.287}{1.6} \right]^2 - \frac{1.287}{0.8}} \]

\[ C_p = 1.429 - \sqrt{2.043 - 1.609} = 1.429 - 0.659 = 0.77 \]

\[ F'_c \text{ (allowable stress)} = C_p \cdot F'_c = 0.77 \times 1,552 = 1,195 \text{ psi} \]

\[ P_c = F'_c \times A = 1,195 \text{ psi} \times 12.25 \text{ in}^2 = 14,639 \text{ lb} \]
TYPES OF COLUMN FORMS

CASE 1. All wood with wooden yokes
   a) Check support requirement of sheathing
   b) Investigate combined bending and axial load in each component of yoke.

CASE 2. Plywood with combination wood and tie bolts yoke
   a) Check support requirement of sheathing;
   b) Check combined bending and axial load in wood yokes; and
   c) Check tension in rod and chain member.
TYPES OF COLUMN FORMS

CASE 3. Wood sheathing with wood and tie bolt yoke, wedged

a) Check support required for sheathing;
b) Check combined bending and axial load in wood yoke;
c) Check tension in tie member; and
d) Check bending stress in cleat or batten

CASE 4. Trussed sheathing, tied with steel strapping

a) Check support requirement of sheathing; and
b) Check hoop tension in steel strap.
## TYPES OF COLUMN FORMS

**CASE 5.** Braced plywood sheathing and steel column clamps

- a) Check support requirement of sheathing;
- b) Follow manufacturer’s recommendations for clamp spacing for satisfying the requirement for support of sheathing.

### Size | Column Size | Weight
--- | --- | ---
36 in. | 6 in. to 23-1/2 in. | 40 lbs/set
48 in. | 9-1/2 in. to 35-1/2 in. | 56 lbs/set
60 in. | 20 in. to 46 in. | 85 lbs/set
### Econ-O-Clamps

<table>
<thead>
<tr>
<th>Clamp Size</th>
<th>Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>24 Inch</td>
<td>21#/Set</td>
</tr>
<tr>
<td>30 Inch</td>
<td>33#/Set</td>
</tr>
<tr>
<td>36 Inch</td>
<td>39#/Set</td>
</tr>
</tbody>
</table>
Using Modular Wall Forms

Horizontal: Gang form creates brick pattern, utilizing steel walees and taper ties.

Vertical: Wall forms set by hand utilizing loop ties.

Pipe brace utilization

Brace Plates attachment procedure.
Using Wedge Bolt Hardware

Step 1: Horizontal wedge bolt is inserted through loop or flat tie.

Step 2: Vertical wedge bolt is inserted into panel and makes secure.

Z tie holder and washer tie in place.

Plate washer and gang washer rod securing steel washer to horizontal gang form.

Concrete Form Hardware

**Wedge Bolt** Standard connection device for Modular Concrete Forms.

**Long Wedge Bolt** Used to connect Modular Panels through Fillers.

**Wafer Tie** Used with Z Tie Holders on Horizontal Walers.

**Z Tie Holder** This attaches double Walers and stiff backs to Modular Form Panels with the use of Wafer Tie.

**Stiff Back Tie** Similar to the Wafer Tie, it is used for Vertical Stiff Backs behind the Walers.

**Gang Form Bolt** Allows Modular Form panels to be ganged with the use of Gang Loop Ties.
Void Forms

- "Void Forms" or "carton forms" creates space between concrete structures and expansive soils, thereby isolating the concrete from the swelling ground.
- Void Form is a temporary support platform for concrete placement until the grade beam or structural slab sets and can support itself across drilled piers, pads, intermittent footings, or other concrete work. The corrugated paper material, lying under structural concrete construction, gradually absorbs ground moisture and loses its strength after the concrete has set, creating a space into which soil can expand without causing damage.

Large Panel Gang Wall Formwork
Temporary Structures

Shoring and Scaffolding

**Column Formwork**

**Plate Girder Formwork**
Slip Forms and Jump Forms

- Tall or repetitive applications
  - The use of slip form results in significant cost benefits when compared with traditional formwork and/or jump form systems.
- Inherent efficiency
  - These are derived from concentrating plant, material resources and labors for a relatively short period - resulting in cost and time benefits in both urban and remote area applications.
- Given adequate plant, disruption to the Slipform process due to adverse weather conditions is unusual.
- Program requirements can be met in any but the most severe of weather conditions.
Slip Forms

- **Slip form is the fastest method of constructing vertical structures.**
  Rate of rise can be 7-8m (23-27 ft) per day, (24 hour slide) or, 2.5-3m (8-10 ft) per day (day shift only) resulting in reduced construction periods and consequent cost savings.

- **No construction joints are necessary and through ties are not used.**
  Water retaining structures and nuclear structures benefit from these features of slip form construction.

- **The modern slip form system has been developed to accommodate the requirements of the most complicated structures.**
  Openings, tapering profiles, reductions in wall thickness and large embedments can be accommodated. The method can now be applied with benefit to a broad range of structures of varying complexity.

Slip Forms

- Slip forms and jump forms are the terms given to self-climbing formwork systems specifically intended to construct concrete walls and columns in high rise buildings and other concrete structures such as chimneys. In slip forms, the climbing is usually carried out continuously during the concrete pour. With jump forms, the climbing is done in steps, following the concrete pour. The term "climb form" is also used to describe a slip form or jump form. The power for the climbing operation can be provided in a variety of ways, but usually by means of hydraulic rams or electric motors connected to climbing feet or screw shafts.

- Slip forms and jump forms usually consist of a number of decks and may also be fitted with trailing screens that are suspended from the form. As with perimeter screens, trailing screens may provide edge protection for persons, prevent materials from falling, provide support for work platforms or a combination of these uses. No two slip forms or jump forms will be identical because their design depends on the size and configuration of the building under construction.
Typical Section of Slip Form System

Typical Section of Jump Form System
CALLIDE

- 210m chimney at Callide, Central Queensland, Australia
  Contractor: Theiss Contractors (Pty) Ltd.

- Chimneys of all configurations are ideal applications for the modern slip form system. Reductions in both diameter and wall thickness can be readily accommodated. Similar economies can be achieved on relatively small chimneys including those with constant cross sections. Work of this nature has now been successfully carried out in many countries worldwide and in a wide range of conditions.
Flour Mill, Doha, Qatar
- Contractor: Taylor Woodrow International
  - Eight silos were slip formed simultaneously with a rate of climb of up to 6m in 24 hours. Two sets of slip form rings were used, with a total of 146 duty lifting jacks, completing the grain and flour silos in just 12 slides and heavy achieving an extremely smooth concrete finish to prevent flour adhesion.

Tolerances for Completed Work
- Thickness of Wall: +3/4 in. and -3/8 in.
- Vertical Deviation
- Total Horizontal Deviation:
  - For height of 100 feet or less, the deviation is limited to maximum 2”.
  - For heights greater than 100 feet, the deviation is limited to H/600.
Questions?

Kamran M. Nemati
nemati@uw.edu
Architecture Hall
Room 130J