Temporary Structures

- Definition
  - Any means or methods which provide temporary support, access, enhancement, or otherwise facilitate the construction of permanent structures.

- Necessity
  - Temporary structures form the interface between design and construction. Most permanent structures simply could not be built without temporary structures.

- Impact on Schedule, Cost, and Quality
  - Losses in time and money will occur if the temporary structures are not planned and coordinated with the same degree of thoroughness as the permanent structures.
Temporary Structures

- The common temporary structures utilized in various construction operations are:
  - concrete formwork construction
  - scaffolding
  - falsework/shoring
  - cofferdams
  - underpinning
  - diaphragm/slurry walls
  - earth-retaining structures
  - construction dewatering.

- This lecture will focus on concrete formwork construction.

Formwork for Concrete

- The term “Temporary Structures” may not fully imply the temporary, since some forms, tie hardware, and accessories are used hundreds of times, which necessitates high durability and maintainability characteristics and design that maximizes productivity.

- Unlike conventional structures, the formwork disassembly characteristics are severely restricted by concrete bond, rigidity, and shrinkage, which not only restricts access to the formwork structure but causes residual loads that have to be released to allow stripping from the concrete which initiates disassembly.
Formwork for Concrete

- Basic objectives in form building:
  - Quality - In terms of strength, rigidity, position, and dimensions of the forms
  - Safety - for both the workers and the concrete structure
  - Economy - the least cost consistent with quality and safety required

- Cooperation and coordination between engineer-architect and the builder or contractor are necessary to achieve these goals.

Objectives of Formwork Building

- Forms mold the concrete to desired size and shape and control its position and alignment.
- Formwork is a temporary structure that supports its own weight + the freshly placed concrete + construction live loads (materials, equipment, and people).
- Size, shape, and alignment of slabs, beams, and other concrete structural elements depend on accurate construction of the forms.
- The formwork must remain in place until the concrete is strong enough to carry its own weight, or the finished structure may be damaged.
In 1908 the use of wood versus steel formwork was debated at the ACI convention. The idea of modular panel forming was also introduced.

By 1910, steel forms were commercially available and used in the field.

Formwork is a classic temporary structure in the sense that:
- it is erected quickly
- highly loaded for a few hours during the concrete placement
- and within a few days disassembled for future use.

Also classic in their temporary nature are the connections, braces, tie anchorages, and adjustment devices which forms need.
Formwork for Concrete

- Traditionally lumber has been the prominent form material.
- Today plywood, metal, plastics, and other materials are commonly used for formwork.
- In the past formwork was built in place, used once, and wrecked.
- Because of high labor costs, today formworks are prefabricated, assembled in large units, and erected by mechanical means, i.e., using crane, and continuing reuse of the forms.

Formwork for Concrete

- Vertical formwork systems (wall and column systems)
- Horizontal shoring systems (flying systems and stationary systems)
- Factors Affecting Formwork and Shoring Designs
Objectives and Goals

- Develop an understanding of the current formwork and shoring systems available today.
- Review typical applications and rental costs for each system.
- Learn the factors that govern formwork and shoring designs – decisions that contractors face.
- Be able to use this knowledge in evaluating formwork systems to fit the project.

Factors Affecting Formwork System Selection
- Safety Accident Prevention!!
- Structure Type and Design
  - Floor-to-floor heights and changes
  - Column and wall layout
  - P/T slabs or conventionally reinforced slabs
  - Construction joint locations
  - Drop caps, slab breaks
  - Existing constraints (Adjacent Buildings)
  - Number of uses of form system
- Crane size and location
- Schedule (Very Important)
- Manpower - Skill Level
- Productivity and cycling of equipment
Factors Affecting Formwork System Selection

- Risk
- Formwork Supplier
  - History with similar projects
  - Engineering expertise
  - Support services
  - Knowledge of support personnel
  - Location
- Buy versus Rent
  - Duration of project
  - Future usage
  - Return on investment
  - Maintenance expense on owned equipment
  - Storage expense

Formwork for Concrete

- Formwork costs constitutes up to 60 percent of the total cost of concrete work in a project.

- The architect and engineer can make savings possible by considering problems of formwork economy at the same time they design the concrete structure.
Vertical Formwork Systems

Wood Forming System

Vertical Formwork Systems

- Placing Labor: 17 percent
- Form Material: 13 percent
- Concrete: 27 percent
- Form Labor: 36 percent
- Rebar in Place: 29 percent

Cost Distribution: Formed Walls

Formwork Costs: Labor vs. Materials
Temporary Structures

Vertical Formwork Systems
Hand-set Forming System

- Application: Walls and Columns
- 50% more productive than snap tie wall systems
- Aluminum Frame with a 5/8” plywood face
- Pour Pressures = 1,200 psf
- Ties on 2’ x 2’ spacings
- Cost $0.85 to $1.00/sf per month

Panel widths vary from 1” to 30”
Panel heights = 3’, 4’, 5’, 6’ and 8’
Vertical Formwork Systems

Hand-set Forming System

- Quick Pre-assembly
- Moveable by Hand
- Hinges and Carts Available
- Braced with 2” x 4”s

Vertical Formwork Systems

Crane Set Forming System

Power Plants

Bridges

Tunnels

Commercial Building
Vertical Formwork Systems

Crane-Set Forming System

- Application: Walls and Columns
- Large Gang Wall Application
- Steel Frame with a 3/4” plywood face – Wt. = 14 psf
- Pour Pressures = 1,500 psf
- Ties on 4’ x 4’ spacing

- Cost $0.90 to $1.10/sf per month
- European Systems: $1.45 to $1.65/sf per mo.

Vertical Formwork System

Gang Wall Forms

- Form Design: Beam with a 55 Kip Aluminum Strongback
- Plywood Face: Typically 3/4”
- Pour Pressures: Up to 1520 psf
- Taper Ties on 6’ x 6’ Spacing

- Weight: 10 Lbs per SF
- Cost $0.65 to $0.75/sf per month
**Vertical Formwork System**
**Gang Wall Forms**

- Radius wall application

**Vertical Formwork System**
**Roll Back Jump Forms**

- Problem:
  - Multi-lift Wall Construction
  - Elevator Cores
  - Safe Access for Rebar, Formwork and Concrete Placing Operations

- Solution:
  Roll back Jump Form
**Vertical Formwork System**

Roll Back Jump Forms

- Standard Gang supported on Roll back Bracket
- Provides an 8’ wide work deck

Form Rolls back 30” to allow access to rebar and form Face.
Vertical Formwork System
Roll Back Jump Forms

- Standard Williams Type Insert
- 1 1/4” Landing Bolt support the Roll Back Bracket

Vertical Formwork System
Elevator Core Form

- Exterior Roll back panels and Interior Cores are Crane Raised
Horizontal Shoring Systems

Hand-Set Shoring Systems: Applications

- Horizontal Formwork for Cast in Place Concrete
- Re-shoring
**Hand-Set Shoring Systems:**

### Applications

- **Hand-Set Shoring** is rated by the capacity per leg:
  - 15 kips per leg
  - Light weight – 6 x 6 frame weighs 44 lbs
  - Frame Heights of 8’ tall available

**Cost:** Varies based on:
- Slab thickness (controls beam spacing)
- Shore Heights (Frame stacks)
- \( H = 10’: \) $0.35 to $0.45/sf
- \( H = 10\) to 15’: Say $0.55/sf
Horizontal Shoring Systems
Parking Garage

Uses Manufacturer Beam Tables for Deck Support

Uses frames to support the beams

Step #1: Beam supports and beam sides are pre-assembled

Step #2: Deck Panels are Pre-Assembled
Step #3: Set Shoring
Frames in place then add pre-assembled Beam Forms

Step #4: Set Pre-Assembled Beam panels in place

Inserts are added to Deck Panels to allow the stripping of the beam sides and shoring
Construction Methods & Materials II
Temporary Structures

**Horizontal Shoring Systems**
Parking Garage

Step #5: Cross braces are removed and the frame legs are folding up to facilitate strip and moving.

Step #6: A forklift lowers the forms and moves to the next concrete placement.

Casters allow forms to easily move through project.

Allows access to move system through set-up equipment.
Horizontal Shoring Systems
Parking Garage

Cost: Varies based on
- Building Geometry (affects post spacing)
- Shore Heights
- Generally: $1.10 to $1.25/sf per month

Application:
Faster cycle times on flat slab structures.
2’ x 6’ Aluminum Deck panels, shore points are on a 6’ x 8’ grid

Horizontal Shoring Systems
Deck

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Faster cycle times on flat slab structures.
2’ x 6’ Aluminum Deck panels, shore points are on a 6’ x 8’ grid

Cost: Varies based on
- Building Geometry (affects post spacing)
- Shore Heights
- Generally: $1.10 to $1.25/sf per month
Temporary Structures

**Horizontal Shoring Systems**

**Deck**
- Drop Heads for Stripping
- Deck removal one day after the concrete placement and prior to post-tensioning
- Reduced cycle time
- Beam Hangers for column capitals

**Truss**

Application:
Used to speed construction on multi-level building.

1st Floor shoring: Trusses are supported on hand-set Shore X Frames.

Cost: Varies based on
- Slab thickness (controls beam spacings)
- Shore Heights (Truss configurations)
- Generally: $0.55 to $0.65/sf per month
Horizontal Shoring Systems

Truss

- 5’ and 6’ deep truss
- 7’ and 10’ cross braces
- Extension legs Jacks
  - 12” – 18”
  - 18” – 24”
  - 24” – 30”
- Lowering devices
- Stripping and flying
- Fillers
Horizontal Shoring Systems
Column Hung

Cost: Varies based on
- Slab thickness (controls truss joist spacing)
- Column Spacing
- Generally: $0.75 to $1.00/sf per month
Horizontal Shoring Systems
Column Hung
**Horizontal Shoring Systems**

**Column Hung**

Column Hung Advantages

- No Reshoring
- Stock Floors before you fly tables to speed interior finishes
- Exterior can Follow closely

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**Horizontal Shoring Systems**
Failure of Formwork

- Formwork failures are the cause of many accidents and failures that occur during concrete construction which usually happen when fresh concrete is being placed.
- Generally some unexpected event causes one member to fail, then others become overloaded or misaligned and the entire formwork structure collapses.

Causes of Failures

- Improper Stripping and Shore Removal
- Inadequate Bracing
- Vibration
- Unstable Soil Under Mudsills, Shoring Not Plumb
- Inadequate Control of Concrete Placement

Formwork collapse causes injuries, loss of life, property damage, and construction delays.
Improper Stripping and Shore Removal

Premature stripping of forms, premature removal of shores, and careless practices in shoring can produce catastrophic results.

Case study: Too early shore removal at Bailey’s Crossroads in Virginia (1973):
- 26-stories + apartment building
- Forms were supported by floors 7-days old or older
- Failure occurred on the 24th floor, where it was shored to the 5-day-old 23rd floor.
- The overloaded 23rd floor failed in shear around one or more columns, triggering a collapse that carried through the entire height of the building.
Inadequate Bracing

- Failure in formwork can be caused by lateral force components or other factors that induce displacement of supporting members.
- Inadequate cross bracing and horizontal bracing of shores is one of the factors most frequently involved in formwork accidents.

**Case study:** New York Coliseum (1955)

- Formwork collapse, where rapid delivery of concrete introduced lateral forces at the top of high shoring.

**Causes of Failures**

**Case study:** New York Coliseum

- Increased diagonal bracing was added to all remaining shoring, following partial collapse of formwork.
Diagonal Bracing:

- High shoring with heavy load at the top is vulnerable to eccentric or lateral loadings. Diagonal bracing improves the stability of such a structure.

Causes of Failures

- Vibration
  - Forms sometimes collapse when their supporting shores or jacks are displaced by vibration caused by:
    - Passing traffic
    - Movement of people and equipment on the formwork
    - the effect of vibrating concrete to consolidate it.
**Causes of Failures**

- **Unstable Soil under Mudsills, Shoring not Plump**
  - Forms should be safe and adequately braced and carry all loads to solid ground through vertical members.
  - Shores must be set plumb and the ground must be able to carry the load without settling.
  - Shores and mudsills must not rest on frozen ground, since moisture and heat from concreting operations, or changing air temperatures, may thaw the soil and allow settlement that overloads or shifts the formwork.
  - Site drainage must be adequate to prevent a washout of soil supporting the mudsill.

- **Inadequate Control of Concrete Placement**
  - The temperature and rate of vertical placement of concrete are factors influencing the development of lateral pressures that act on the forms.
  - If temperature drops during construction operations, rate of concrete placement has to slow down to prevent a buildup of lateral pressure overloading the forms.
Planning for Safety

- OSHA (Occupational Safety and Health Administration) regulations, ACI recommendations, and local code requirements for formwork should be followed.
  - Supervision and Inspection
  - Platform and Access for Workers
  - Control of Concreting Practices
  - Improving Soil Bearing and Bracing
  - Shoring and Reshoring
  - Relationship of Architect, Engineer and Contractor
  - Maintaining and Coordinating Tolerances
  - Preparing a Formwork Specification

Formwork Materials & Accessories

- Practically all formwork jobs require some lumber.
- Local supplier will advise what material and sizes are in stock or promptly obtainable, and the designer or builder can proceed accordingly.
- Southern yellow pine and Douglas fir, sometimes called Oregon pine are widely used in structural concrete form.
- They are easily worked and are the strongest in the softwood group. Both hold nails well and are durable.
- They are used in sheathing, studs, and wales.
Lumber which has been surfaced in a planing machine to attain smoothness of surface and uniformity of size is called “dressed” lumber.

The surfacing may be on one side (S1S), one edge (S1E), two sides (S2S), two edges (S2E), or combination of sides and edges (S1S1E, S1S2E, S2S1E) or on all four sides (S4S).

Dressed lumber is generally used for formwork, because it is easier to handle and work, but rough sawn boards and timbers may be used in bracing and shoring, or as a form surfacing material to secure a special texture effect in the finished concrete.
Form Materials and Accessories

- Minimum sizes of both rough and dressed lumber are specified by the American Softwood Lumber Standards, PS 20-70. It changes the dimensions to equate green and dry lumber.
- Lumber is commonly referred to by its nominal size.
- Minimum sizes for green lumber are selected so that as moisture is lost, it becomes the same size as dry lumber.

Specified actual size of a 2×4 for different moisture contents and finishes.

Form Materials and Accessories

- Table 4-1B shows actual dimensions and cross section properties of American Standard lumber at 19 percent moisture content.
- Actual, not nominal, sizes must always be used for design.
Design for formwork is based on the allowable or working stresses.

Allowable stress depends on so many factors including the species of wood, grade, cross section, moisture content, and load duration.

Table 4-2 shows base design values for several species of wood in common use for formwork.

### Plywood

- Plywood is widely used for job built forms and prefabricated form panel systems.
- Plywood is a flat panel made of a number of thin sheets of wood. A single sheet in the panel may be referred to as a ply, or layer.
- A layer may consist of a single ply or it may be two or more plies laminated together with their grain direction parallel.
### Form Materials and Accessories

**Plywood**

- Table 4-3 shows the effective section properties for plywood.

**TABLE 4-3: EFFECTIVE SECTION PROPERTIES FOR PLYWOOD (12-IN. WIDTHS)*
FACE PLYES OF DIFFERENT SPECIES FROM INNER PLYES**

<table>
<thead>
<tr>
<th>Sanded plywood net thickness, in.</th>
<th>Minimum number of layers</th>
<th>Effective thickness for shear, all grades using exterior glue</th>
<th>12-in. width, used with face grain parallel to span</th>
<th>12-in. width, used with face grain perpendicular to span</th>
<th>Approximate weight, lb</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Area for torsion and compression, in.²</td>
<td>Moment of inertia, in.⁴</td>
<td>Effective section module, kS in.⁴</td>
<td>Rolling shear constant, lb/in²</td>
</tr>
<tr>
<td>3/4</td>
<td>3</td>
<td>0.867</td>
<td>0.008</td>
<td>0.059</td>
<td>2.010</td>
</tr>
<tr>
<td>3/4</td>
<td>5</td>
<td>1.307</td>
<td>0.022</td>
<td>0.125</td>
<td>3.086</td>
</tr>
<tr>
<td>3/4</td>
<td>7</td>
<td>1.947</td>
<td>0.077</td>
<td>0.238</td>
<td>4.466</td>
</tr>
<tr>
<td>5/4</td>
<td>5</td>
<td>2.475</td>
<td>0.129</td>
<td>0.339</td>
<td>5.824</td>
</tr>
<tr>
<td>1/4</td>
<td>7</td>
<td>3.086</td>
<td>0.197</td>
<td>0.412</td>
<td>6.752</td>
</tr>
<tr>
<td>3/8</td>
<td>7</td>
<td>3.684</td>
<td>0.278</td>
<td>0.515</td>
<td>8.050</td>
</tr>
</tbody>
</table>

*Use listed kS value in bending calculations and use J only in deflection calculations. Properties taken from 1998 edition of Reference 4-B apply for all product standard grades except Structural I and Marine. If B-B Plywood grade is used, values from Reference 4-9 (somewhat slightly higher) can be used for design.

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**Form Materials and Accessories**

**Plywood**

- Plywood at the bottom-face grain parallel to span-is used the strong way. With face grain perpendicular to the span direction, the specimen at the top is used the weak way.
Loads and Pressures

- Formwork for concrete must support all vertical and lateral loads that may be applied until such time as these loads can be carried by the concrete structure itself.

- Loads on the forms include:
  - The weight of reinforcing steel and fresh concrete
  - the weight of the forms themselves
  - various live loads imposed during the construction process

- Dumping of concrete, movement of construction equipment, and action of the wind may produce lateral forces which must be resisted by the formwork to prevent lateral failure.

Vertical Loads

- Vertical loads on formwork include:
  - the weight of reinforced concrete
  - the weight of forms themselves (dead load)
  - the live loads imposed during the construction process (material storage, personnel and equipment)

- The concrete weighs 150 pcf, it will place a load on the forms of 12.5 psf for each inch of slab thickness. i.e., a 6-inch slab would produce a dead load of $12.5 \times 6 = 75$ psf (neglecting the weight of the form)
Vertical Loads

- ACI Committee 347 recommends that both vertical supports and horizontal framing components of formwork should be designed for a minimum live load of 50 psf of horizontal projection to provide for weight of personnel, runways, screeds and other equipment.
- When motorized carts are used, the minimum should be 75 psf.
- Regardless of slab thickness, the minimum design value for combined dead and live loads should be 100 psf, or 125 psf if motorized carts are used.

Live load including power buggy and the concrete crew

(A minimum live load of 75 psf is recommended for design where power buggies are used)
Vertical Loads

- Table 5-1 shows vertical loads on forms for various types of slabs of varying thickness (using minimum live load of 50 psf, and neglecting weight of the form, which may be added by designer).

- When slab form members are continuous over several supporting shores, dumping concrete on one span of the form member may cause uplift of the form in other spans.

- Forms must be designed to hold together under such conditions.

- If form members are not secured to resist this uplift, they should be built as a simple pan.
Formwork Design

- When the material for formwork have been chosen, and the anticipated loading estimated, a form should be designed strong enough to carry the anticipated loads safely, and stiff enough to hold its shape under full load.

- At the same time the builder or contractor wants to keep costs down by not overbuilding the form.

Form Materials and Accessories

- Practically all formwork jobs require some lumber.
- Local supplier will advise what material and sizes are in stock or promptly obtainable, and the designer or builder can proceed accordingly.
- Southern yellow pine and Douglas fir, sometimes called Oregon pine are widely used in structural concrete form.
- They are easily worked and are the strongest in the softwood group. Both hold nails well and are durable.
- They are used in sheathing, studs, and wales.
Form Materials and Accessories

Typical wall form with components identified. Plywood sheathing is more common than board sheathing material.

Form Materials and Accessories

Parts of typical slab formwork
Form Materials and Accessories

Ties

- A concrete form tie is a tensile unit adapted to holding concrete forms secure against the lateral pressure of unhardened concrete.
- A wide variety of ready-made ties with safe load ratings ranging from 1000 lb to more than 50000 lb are used today.
- They consist of internal tension unit and external holding device, and are manufactured in two basic types:
  - Continuous single member
  - Internal disconnecting type
Ties

Some commonly available single member ties.

Continuous Single Member Ties

- Continuous single member, in which the tensile unit is a single piece, and a special holding device is added for engaging the tensile unit against the exterior of the form.

- Some single member ties may be pulled as an entire unit from the concrete; others are broken back a predetermined distance, some are cut flush with the concrete surface.
Internal disconnecting Type Ties

- Internal disconnecting type, in which the tensile unit has an inner part with threaded connections to removable external members which make up the rest of the tensile unit. They generally remain in the concrete.

Ties

- The two types of tying devices are identified commercially by various descriptive names, such as form clamps, coil ties, rod clamps, snap ties, etc.

- Except for taper ties, the continuous single member type is generally used for lighter loads, ranging up to about 5000 lb safe load.

- The internal disconnecting type of tie is available for light or medium loads but finds its greatest application under heavier construction loads (up to about 70,000 lb).