Formwork and its associated labor is the largest single cost segment of the concrete structural frame – generally more than 50%

1. DEFINITIONS

Flying forms are large prefabricated units of formwork incorporating support, and designed to be moved from place to place.

A form is a temporary structure or mold for the support of concrete while it is setting and gaining sufficient strength to be self-supporting.

Formwork is a total system of support for freshly placed concrete including the mold or sheathing which contacts the concrete as well as all supporting members, hardware, and necessary bracing.

Ganged forms are prefabricated panels joined to make a much larger unit for convenience in erecting, stripping, and reusing; usually braced with wales, strongbacks, or special lifting hardware.

2. STRUCTURAL AND ARCHITECTURAL DESIGN CONSIDERATIONS FOR ECONOMICAL FORMWORK

At times, the construction loads are the maximum loads to which a structure will ever be subjected. Therefore, it is important that the Architect/Engineer consider economical formwork procedures with the same priority as other architectural or structural design considerations, recognizing that formwork costs and construction safety are affected by these decisions. Project specifications may also influence formwork design and speed of construction. Examples of such specification items are stripping time, tolerances, concrete finish requirements, strength of concrete, and reinforcing steel and accessory requirements.

Don’t forget to “keep it simple”—form standardization and reuse is the key to economy.

3. FLOORS

Column Capitals and Drop Panels: These are part of the floor structural system and generally quite expensive to form. Consideration of shear head reinforcing steel within the floor slab should be given prior to the decision to use them. If column capitals or drop panels must be used, strive to use the same size and shape throughout the project.

Construction Joints: Exact location of construction joints should be the Contractor’s prerogative. However, permissible areas for such joints should be shown on the structural drawings. Proper joint location will maximize form reuse, thereby reducing costs.

Core Areas: Many projects contain core areas for elevators, stairs, and mechanical chases. The core may require more labor than an entire typical floor for a high-rise building. Reducing the number and/or standardizing floor opening sizes and locations within the core will help reduce costs. Repeating the core framing pattern on as many floors as possible will increase form reusability and reduce costs.

Electrical and Mechanical Considerations: Proper location of inserts and/or penetrations should be shown on the structural drawings. Electrical and mechanical attachments to the formwork impede stripping of formwork. Sleeving or block-outs speed construction.

Floor-to-Floor Heights: Repetitive floor heights produce efficiency in materials and lower cost due to less adjustment in shoring and column forms. Low floor-to-floor heights increase labor productivity.

Modular Dimensions: Repetitive modules assist in achieving maximum efficiency. Modular dimensions tend to reduce the possibility of errors.

Overhangs: Perimeter overhangs at floors and roofs, such as spandrel projections, which project beyond the floor below should be eliminated whenever possible, especially at corners. In addition, large covers over the stairwells are difficult and costly to form.

Sloped or Stopped Surfaces: The underside of all flat slabs, joists, and dome systems should be kept level for maximum economy. Sloping of floor surfaces should be accomplished by varying the structural slab thickness or by the use of concrete fill. Depressions for terrazzo, tile, etc., should be accomplished by varying the top slab surface rather than by adjusting formwork beneath the slab.
4. BEAMS

**Dimensions:** For a line of continuous beams, keep the beam size constant and vary the reinforcement from span to span. See Figures 1 and 2.

**Drop Beams with Joist Systems:** Allow for minimum tees and lugs at sides of beams. Try to keep difference in elevation between bottom of beam and bottom of floor system in modular lumber dimensions. See Figure 2.

**Width:** Beams should be as wide as, or wider than, the columns into which they frame. See Figures 1 and 2.

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5. COLUMNS

**Exposed Surfaces:** Chamfer corners to eliminate leakage and produce a better quality finished product.

**Location:** For maximum economy, standardize column location in a uniform pattern in both directions.

**Orientation:** Use same orientation for as many rectangular columns as possible.

**Shape:** Use same shape as often as possible throughout any given floor and vertically from floor to floor. Square or round columns are the most economical. Use rectangular shapes only when architectural, structural, or flying form requirements so dictate.

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**Figure 1 – Spandrel Beams**

**Figure 2 – Beams and Joists**
6. WALLS

Architectural Treatment: Should be approached very cautiously. Beautiful architectural walls are possible with today's many varieties of form liners but concrete mix design, color variation, concrete placement procedures, and weather conditions make them more difficult and costly. If architectural walls are required, use reveal strips at all construction joints. See Figure 3.

Brickledges: Should be kept at a constant height with a minimum number of steps. Thickness as well as height should be in dimensional units of lumber, approximating as closely as possible those of the masonry to be placed thereon. Brickledge locations and elevations should be dimensioned on the structural drawings.

Footing Elevations: Should be kept at a constant elevation along any given wall if possible. This facilitates the use of gang forms. If footing steps are required, use minimum number possible and in whole foot vertical steps.

Openings: These can add to the forming time and offer the potential for honeycombing. Careful design is required to achieve an acceptable wall.

Pilasters: One of the more costly items in wall construction. Minimize or standardize dimensions to facilitate gang forming. Minimum offset should be 6 in. to utilize standard inside corner forms, increased offsets should be in 2 in. increments. Pilaster widths should be in 6 in. increments to utilize available prefabricated modular form sizes (12, 18, and 24 in.). Increases in pilaster depth should be in 2 in. increments. Consideration should be given to thickening the wall in lieu of pilasters. See Figure 4.

Thickness: Constant wall thickness facilitates the reuse of forming equipment. When kept the same throughout a project, it minimizes the possibility of errors in the field. Sufficient wall thickness to permit the proper placing and vibrating of concrete should be maintained.
7. BATTERED WALLS

Battered walls are one of the more costly items in formwork preparation. Maintain a constant rate of batter so that form tie sizes are minimized. By having a changing wall width at the bottom of a wall with a varying height, a uniform rate of batter may be maintained. Wales are parallel to the top of the wall; form tie sizes are minimized. See Figures 5 and 6.

A warped wall occurs when the rates of batter at each wall end are not identical. Changing wall heights and constant wall widths at top and bottom cause a changing rate of batter. In such instances, each form tie along the wale will be a different size, thereby increasing labor and form tie material costs. Warped walls should be avoided.

Determining Rate of Batter

Comparing the rates of batter at each wall end will indicate if a uniform batter exists or if the wall is warped.

Rate of Batter

\[ \text{Rate of Batter} = \frac{\text{Bottom Width} - \text{Top Width}}{\text{Wall Height}} \]

Example (see Fig. 6):

Wall Height at End “A” = 20 ft
Wall Height at End “B” = 16 ft
Bottom Width at End “A” = 22 in.
Bottom Width at End “B” = 20 in.
Top Width = 12 in.

Rate of Batter (at End “A”)

\[ = \frac{22 \text{ in.} - 12 \text{ in.}}{20 \text{ ft}} = 0.5 \text{ in./ft} \]

Rate of Batter (at End “B”)

\[ = \frac{20 \text{ in.} - 12 \text{ in.}}{16 \text{ ft}} = 0.5 \text{ in./ft} \]

Therefore, for this example, the rate of batter is uniform and form ties positioned in wales that are parallel to the top of the wall will all be the same size. Note that bottom wale is horizontal and each form tie could be a different size.

Cost Considerations

BATTERED WALLS WERE ORIGINALLY DEVELOPED TO SAVE CONCRETE VOLUME. AT ONE TIME, MATERIAL COSTS WERE HIGH IN COMPARISON TO LABOR COSTS. TODAY, THE OPPOSITE IS TRUE AND THE ARCHITECT/ENGINEER SHOULD SERIOUSLY CONSIDER ELIMINATING ANY BATTERED WALLS AND USE A CONSTANT THICKNESS WALL.

The use of adjustable ties, such as coil ties and inner tie rods, permit variations in the setback. Ties can be grouped and fewer sizes of ties would be required as compared to fixed length ties, such as snap ties.

The use of prefabricated modular forms with predetermined tie locations will generally require a different size tie at each location thereby increasing the number of tie sizes.
8. MISCELLANEOUS ITEMS

Dowel Bar Coupler: Use of dowel bar coupler systems eliminates the need to drill and repair formwork for location of dowel reinforcing bars. Costly form stripping and wear/tear of formwork is also eliminated. See Figure 7.

Formwork Accessories: Allow 1 in. increments on ties. Avoid fractional wall thickness, utilizing instead inventories of standard form ties. Use standard sizes of readily available prefabricated modular formwork for constant wall thicknesses, as shown in the Figure 4 for pilaster offsets. Refer to manufacturers’ catalogs for standard size formwork components and form ties options that are available.

Lap-Splice Connector Systems: Similar to dowel bar couplers, using a lap-splice connector system eliminates the need to drill and repair formwork for reinforcing bars which extend from one pour to an adjoining pour. The assembly is attached to the formwork at a construction joint. After the forms are stripped, the lap-splice reinforcement is field straightened. See Figure 8.

Rebar Accessories: Proper placement and cover of reinforcing bars in slabs, walls, beams and columns is the key to long-term performance and prevention of unsightly rust stains and spalling of concrete. Refer to the CRSI Manual of Standard Practice, Placing Reinforcing Bars, and Reinforcement Anchorages and Splices for suggested criteria.

Ties: Galvanized wire snap ties should be avoided if they are being used to eliminate a future rust condition. After the snap tie is broken back, the base metal of the tie will be exposed and allow rusting to take place, thereby wasting the premium paid for galvanizing. Use of stainless steel wire snap ties is an expensive solution. Other variations of ties are available to solve this condition and do so at lower costs. Contact a local supplier.

9. TEN STEPS TO FORMWORK ECONOMY

1. Study the structure as a whole.
2. Prepare freehand alternative sketches comparing all likely structural framing systems.
3. Establish column locations as uniformly as possible keeping orientation and size constant wherever possible.
4. Select preliminary member sizes from CRSI Design Handbook or other appropriate reference material and “rules of thumb” (i.e., standard dimensions).
5. Make cost comparisons based on sketches from Step 2 quickly and roughly, but with an adequate degree of accuracy.
6. Select the best balance between cost of structure and design considerations.
7. Distribute drawings of selected framing scheme to all Architect/Engineer team members to reduce unnecessary future changes.
8. Plan your structure. Visualize how forms would be constructed. Keep beams and columns simple without haunches, brackets, pilasters, batters, widened ends or offsets. Standardize member sizes for maximum reuse of forms.
9. During final design, place most emphasis on those items having greatest financial impact on total structural frame cost.
10. Plan your project specifications to minimize construction costs and time by including items such as early stripping time for formwork and high early strength concrete mix.
10. FINAL CONSIDERATIONS

FORMWORK is the largest single cost segment of the concrete structural frame—generally more than 50%! These costs are affected by such variables as geographic location, transportation, wage rates, strength of concrete, floor height, foundation, and concrete mix design.

MATERIALS: Concrete is the most universally available construction material! It has the advantage of being locally supplied with other necessary components such as reinforcing steel and standard forms from readily available local inventories.

SPEED OF CONSTRUCTION: Because standard forms and reinforcing steel are held in local inventories, construction can begin immediately upon an owner’s decision to build. Local product availability lends itself to modern construction management approaches such as “fast-track” techniques, allowing last minute changes with minimum delays.

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Formwork-Related Engineering Data Reports

The following formwork-related Engineering Data Reports may be of interest to the reader:

- No. 46  Wide-Module Joist Systems - Revisited
- No. 43  One-Way Concrete Joist Construction: Steel Lap Pan Forming System
- No. 40  Construction Tolerance Conflicts in Reinforced Concrete
- No. 32  Engineering for Rapid Construction Cycles
- No. 30  Economical Concrete Construction

These reports can be downloaded from the CRSI web site.

CRSI Web Site

The reader is encouraged to visit the Institute’s web site at www.crsi.org for:

- Descriptions of CRSI publications and software, and ordering information
- Institute documents available for downloading
- Information on the CRSI Design Awards competition
- General information on the CRSI Foundation
- Membership in CRSI and member web links
- Technical information on continuously reinforced concrete pavement
- Technical information on epoxy-coated reinforcing bars

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