

3.1 Introduction:

This chapter deals with formwork design and construction. All formwork should be well designed before construction begins. The designing required will depend on the size, complexity, and materials (considering reuses) of the form. Formwork should be designed for strength and serviceability. System stability and member buckling should be investigated in all cases.

. Formwork should be designed well, so that it will safely support all vertical and lateral loads that might be applied until such loads can be supported by the concrete structure. Loads on the forms include the weight of reinforcing steel, fresh concrete, the weight of the forms themselves and various live loads imposed during the construction. In addition an action of the wind may produce lateral forces which must be resisted by the formwork to prevent lateral failure. Vertical and lateral loads should be carried to the ground by the formwork system or by the in-place construction that has adequate strength for that purpose.

In this chapter also we will strict ourselves with the construction of Timber Formwork. Formwork should be constructed so that concrete slabs, walls, and other members will have the correct dimensions, shape, alignment, elevation, and position within established tolerances.

Responsibility for the design of the formwork rests with the contractor or the formwork engineer hired by the contractor.

3.2 Loads and Pressures on Forms:

Forms design must consider conditions such as unsymmetrical placement of concrete, impact from machine delivered concrete, uplift, and concentrated loads produced by storing supplies on the freshly placed slab. Rarely will there be precise information as to loads that will come on the forms, and the designer must make some safe assumptions which will hold good for condition generally encountered. The following section are a guide to the designer for determining

the loading on which to base form design for ordinary conditions normally applicable to structural concrete.

3.2.1 Lateral Pressure of fresh Concrete on Formwork:

Loads imposed by fresh concrete against wall or column forms differ from the gravity load on a horizontal slab or beam form. The freshly placed concrete behaves temporarily like a fluid, producing a hydrostatic pressure that acts laterally on the vertical forms.

The pressure exerted by concrete on formwork is determined primarily by several or all of the following factors:

1. Rate of placing concrete in forms.
2. Temperature of concrete.
3. Weight or density of concrete.
4. Cement type or blend used in the concrete.
5. Method of consolidating the concrete.
6. Method of placement of the concrete.
7. Depth of placement.
8. Height of form.

3.2.2 Calculation of loads on Formwork:

Concrete is a mixture of sand and aggregate that is bonded together by a paste of cement and water. Admixtures are commonly used in concrete mixes. Additives include liquids, solids, powders, or chemicals that are added to a concrete mix to change properties of the basic concrete mixture of water, cement, sand, and aggregate. They can accelerate or retard setting times, decrease water permeability, or increase strength, air content, and workability. The pressure of concrete on formwork depends on the type of cement and admixtures in the concrete mix.

When concrete is first mixed, it has properties lying between a liquid and a solid substance. It is best described as a semiliquid and is usually defined as a plastic material. With the passage of time, concrete loses its plasticity and

changes into a solid. This property of changing from a plastic to a solid makes concrete can be easily shaped by forms before attaining its final state.

- Lateral Pressure equations:

The American Concrete Institute has devoted considerable time and study to form design and construction practices. ACI Committee (347) identifies the maximum pressure on formwork as the full hydrostatic lateral pressure, as given by the following equations:

$$p = wh \text{ (lb/ft}^2\text{)} \quad (3.1a)$$

$$p = \rho gh \text{ (kPa)} \quad (3.1b)$$

The set characteristics of a mixture should be understood, and using the rate of placement, the level of fluid concrete can be determined. For columns or other forms that can be filled rapidly before stiffening of the concrete takes place, (h) should be taken as the full height of the form or the distance between horizontal construction joints when more than one placement of concrete is to be made. When working with mixtures using newly introduced admixtures that increase set time or increase slump characteristics, such as self-consolidating concrete, Eq. [(3.1a) (3.1b)] should be used until the effect on formwork pressure is understood by measurement.

i- Inch-pound version:

For concrete having a slump of 7 in. or less and placed with normal internal vibration to a depth of 4 ft or less, formwork can be designed for a lateral pressure as follows:

For columns:

$$p_{max} = C_w C_c \left[150 + \frac{9000R}{T} \right] \quad (3.2-i)$$

With a minimum of $600C_w \text{ lb/ft}^2$, but in no case greater than (wh).

For walls: with a rate of placement of less than 7 ft/h and a placement height not exceeding 14 ft:

$$p_{max} = C_w C_c \left[150 + \frac{9000R}{T} \right] \quad (3.3-i)$$

With a minimum of $600 C_w \text{ lb/ft}^2$, but in no case greater than (wh).

For walls: with a placement rate less than 7 ft/h where placement height exceeds 14 ft, and for all walls with a placement rate of 7 to 15 ft/h:

$$p_{max} = C_w C_c \left[150 + \frac{43,400}{T} + \frac{2800R}{T} \right] \quad (3.4-i)$$

With a minimum of $600 C_w \text{ lb/ft}^2$, but in no case greater than (wh).

ii-SI version: For concrete having a slump of 175 mm or less and placed with normal internal vibration to a depth of 1.2 m or less, formwork can be designed for a lateral pressure as follows:

For columns: For determining pressure of concrete on formwork ACI 347 defines a column as a vertical structural member with no plan dimensions greater than 2m. For concrete with a slump (175 mm):

$$p_{max} = C_w C_c \left[7.2 + \frac{785R}{T+17.8} \right] \quad (3.2-ii)$$

With a minimum of 30 C_w kPa, but in no case greater than ρgh.

For walls: For determining pressure of concrete on formwork ACI 347 defines a wall as a vertical structural member with at least one plan dimension greater than 2m. Two equations are provided for wall form pressure:

- a- With a rate of placement of less than 2.1 m/h and a placement height not exceeding 4.2 m :

$$p_{max} = C_w C_c \left[7.2 + \frac{785T}{T+17.8} \right] \quad (3.3-ii)$$

With a minimum of 30 C_w kPa, but in no case greater than ρgh.

- b- with a placement rate less than 2.1 m/h where placement height exceeds 4.2 m, and for all walls with a placement rate of 2.1 to 4.5 m/h:

$$p_{max} = C_w C_c \left[7.2 + \frac{1156}{T+17.8} + \frac{244R}{T+17.7} \right] \quad (3.4-ii)$$

With a minimum of 30 C_w kPa, but in no case greater than ρgh.

- Alternatively, a method based on appropriate experimental data can be used to determine the lateral pressure used for form design.
- If concrete is pumped from the base of the form, the form should be designed for full hydrostatic head of concrete (wh) plus a minimum allowance of 25% for pump surge pressure. In certain instances, pressures can be as high as the face pressure of the pump piston.
- Caution is necessary and additional allowance for pressure should be considered when using external vibration or concrete made with shrinkage compensating or expansive cements. Pressures in excess of the equivalent hydrostatic head can occur.

3.2.3 Vertical loads on Formwork:

In addition to lateral pressure, vertical loads are also imposed on formwork. Vertical loads consist of dead and live loads. The weight of formwork, the weight of the reinforcement and freshly placed concrete is dead load. The live load includes the weight of the workers, equipment, material storage, runways, and impact.

Vertical loads assumed for shoring and reshoring design for multistory construction should include all loads transmitted from the floors above as dictated by the proposed construction schedule.

The majority of all formwork involves concrete weighting 22-24 KN/m^3 . minor variations in this weight are not significant, and for these majority cases 24 KN/m^3 including weight of reinforcing steel is commonly assumed for design. Formwork weights vary from as little as 0.15 to 0.7 KN/m^2 . When the formwork weight is small in relation to the weight of the concrete plus live load, it is frequently, neglected.

ACI committee 347 recommends that both vertical supports and horizontal framing components of formwork should be designed for a minimum live load of 50 lb/ft^2 (2.4 KN/m^2) of horizontal projection to provide for weight of workmen, runways, screeds and other equipment. When motorized carts are

used, the minimum should be 75 lb/ft² (3.6 KN/m²). Regardless of slab thickness, the minimum design load for combined dead and live loads should not be less than 100 lb/ft² (4.8 KN/m²) or 125 lb/ft² (6.0 KN/m²) if motorized carts are used.

3.2.4 Horizontal loads on Formwork:

Horizontal loads include the assumed value of load due to wind, dumping of concrete, inclined placement of concrete, cable tensions and equipment. The impact of wind increases with height. Horizontal loads should be not less than 100 lb/ft (1.5 kN/m) of floor edge or 2% of total dead load on the form.

Bracing should be provided to withstand the sidesway effects which occur when concrete is placed unsymmetrical on a slab form.

Wall form bracing should be designed to meet the minimum wind load requirements of the local building code with adjustment for shorter recurrence interval. For wall forms exposed to the elements, the minimum wind design load should not be less than 15 lb/ft² (0.72 kPa). Bracing for wall forms should be designed for a horizontal load of at least 100 lb/linear ft (1.5 kN/m) of wall length, applied at the top. Wall forms of unusual height or exposure should be given special consideration.

3.3 Design of Formwork:

The design of job-built forms may be considered largely as bending members. The bending members usually span several supports and are therefore indeterminate. Assumptions and approximations are made that simplify the calculations and facilitate the design process.

After establishing the appropriate design loads, the sheathing and supporting members are analyzed or designed in sequence.

Formwork or bending members (sheathing, joists, studs, stringers, or wales) are considered uniformly loaded and supported on (1) a single span, (2) two spans or (3) three or more spans. The uniform load assumption is a common practice unless the spacing of point loads exceeds one-third to one-half of the span between supports, in which case the worst loading condition is investigated. Each bending member should be analyzed or designed for bending moment, shear, and deflection.

Falsework or vertical supports (shoring) and lateral bracing (if applicable) must be analyzed or designed for either compressive or tensile loads.

Bearing stresses at supports must be investigated for all members (except for the sheathing) to ensure against crushing.

Using the methods of engineering mechanics, the maximum values expressed in customary units of bending moment, shear, and deflection developed in a uniformly loaded, simply supported beam of uniform cross section are given in (Table 3).

(Table 3)

Maximum bending, shear, and deflection in a uniformly loaded beam:

Type	Support Conditions		
	1 Span	2 Spans	3 Spans
Bending moment	$M = \frac{wl^2}{8}$	$M = \frac{wl^2}{8}$	$M = \frac{wl^2}{10}$
Shear	$V = \frac{wl}{2}$	$V = \frac{5wl}{8}$	$V = \frac{3wl}{5}$
Deflection	$\Delta = \frac{5wl^4}{384 EI}$	$\Delta = \frac{wl^4}{185 EI}$	$\Delta = \frac{wl^4}{145 EI}$

If we equate allowable unit stresses to the maximum unit stresses developed in a beam subjected to a uniformly distributed load (w) lb/ft (KN/m), expressions can be derived for the maximum allowable span length. Therefore, knowing the design loads and member section properties, a maximum allowable span length can be computed.

Table (4) contains expressions for maximum allowable span length as governed by moment, shear, and deflection. The reader may wish to derive these expressions from basic principles. The moment expressions are based on the maximum positive or negative moment. The maximum shear considered is the shear that exists at (d) distance from the support, where (d) is the depth of the member. Shear considerations for plywood vary from those accorded sawn lumber because of the cross-directional way in which the plies of the plywood are assembled. The wood fibers in these plies roll at stresses below the fiber shear strength parallel to the grain, hence the name rolling shear.

Deflection of forms must be limited to minimize unsightly bulges in the resulting concrete surface. The deflection limit may be specified as a fraction of span ($\ell/240$), as a limit ($1/8$ in), or as the smaller of the two.

The architect/engineer must decide on the deflection limit for the formwork based on bulging and sagging that can be tolerated in the surfaces of the finished structure. The casting of test panels may be warranted in some cases. Limiting deflection to ($1/360$) of the span is acceptable in many cases where

surfaces are coarse-textured and there is little reflection of light. Three design equations for deflection are given in (Table 4). Alternatively, the may wish to compute the required size of the members when the design loads and span lengths are known. The same basic principles apply.

3.3.1 Section properties:

Section properties for selected thicknesses of plyform are given in (Table 5). These section properties reflect that various species of wood used in manufacturing plywood have different stiffness and strength properties. Those species with similar properties are assigned to a species group. To simplify plywood design, the effects of using different species groups in a given panel as well as the effects of the cross-banded construction of the panel have been taken into consideration in establishing the section properties.

In calculating these section properties, all plies were transformed to properties of the face ply. As a result, the designer need not be concerned with the actual panel layup but only with the allowable stresses for the face ply and the given section properties of (Table 5). The section properties of (Table 5) are generally the minimums that can be expected. Hence the actual panel obtained in the marketplace will usually have a section property greater than that represented in the table.

The plyform design values presented in (Table 5) are based on wet strength and 7-day load duration, so no further adjustment in these values is required except for the modulus of elasticity. The modulus shown is an adjusted value based on the assumption that shear deflection is computed separately from bending deflection. These values should be used for bending deflection calculation (which is usual case). To calculate shear deflection, the modulus should be reduced to 1,500,000 psi for class I and structural plyform and to 1,300,000 psi for class II plyform.

Section properties for selected members of standard dressed (S4S) sawn lumber are given in (Table 6). Typical base design values for visually graded dimension lumber are furnished in (Table 7). This table is simplified and brief and is primarily intended as a resource to accompany the examples and

problems of this text. Those who require more detailed information with respect to section properties and design values should obtain (ANSI/AF&PA NDS 2005).

3.3.2 Adjustment Factors for Lumber Stresses:

The base design values in (Table 7) must be modified by applicable adjustment factors that are appropriate for the conditions under which the wood is used.

The AFPA-NDS (AFPA, 2005) provides for adjustment of the lumber reference design values (F), such as those given in (Table 8 - Table 9), by a series of multipliers yielding the allowable design values (F') for stress as follows:

- Bending:

$$F'_b = F_b \times C_D \times C_M \times C_L \times C_F \times C_{fu} \times C_r \times [C_t \times C_i]$$

- Shear:

$$F'_v = F_v \times C_D \times C_M \times [C_t \times C_i]$$

- Bearing:

$$F'_{c\perp} = F_{c\perp} \times C_M \times C_b \times [C_t \times C_i]$$

- Compression:

$$F'_c = F_c \times C_D \times C_M \times C_F \times C_P \times [C_t \times C_i]$$

- Elastic Modulus:

$$E' = E \times C_M \times [C_t \times C_i]$$

$$E'_{\min} = E_{\min} \times C_M \times [C_t \times C_i \times C_T]$$

Some of the adjustment factors (in brackets) only apply to truss members (buckling stiffness factor, C_T), when the member is incised (incising factor, C_i) or when the temperature is $> 100^\circ\text{F}$ (temperature factor, C_t), and thus have only rare uses in formwork. The remaining factors are discussed below:

- **Load Duration Factor (C_D):**

The adjustment for load duration (C_D) reflects the ability of wood to exhibit increased strength under shorter periods of loading.

For most formwork, an adjustment of $C_D = 1.25$ is applied; however, when the components are reused for longer cumulative durations at maximum level, C_D should be appropriately reduced.

- **Moisture Factor (C_M):**

Wood gains in strength as it loses moisture in a range below the fiber saturation point (about 30% moisture content). The basic design values are established for lumber that has a moisture content of 19% or less, typical of air-dried lumber. When the exposure is such that the wood moisture content will exceed 19% for an extended period of time, the design values should be multiplied by the C_M values indicated in (Table 7).

- **Size Factor (C_F):**

Tests indicate that member overall size affects the failure stress. To account for these variations, the size factor (C_F) as shown in Table (9) is applied to the bending and compression basic design values. Note that the size factor does not apply to the basic design values of Southern Pine, whose basic design values in (Table 8 – Table 9) are pre-adjusted to reflect most of the size effect.

- **Flat-Use Factor (C_{fu}):**

Lumber loaded on its wide face and bending about its weak axis (y–y) exhibits a slightly higher failure stress. To reflect these variations, the flat-use factor (C_{fu}) adjustments in (Table 8) may be applied to the basic design values for bending stress.

- **Beam-Stability Factor (C_L):**

The AFPA-NDS (AFPA, 2005) provides equations for determining the beam-stability factor (C_L), an adjustment less than 1.0, when the compression edge of a beam may become unstable. For sawn lumber, however, the AFPA-NDS also provides prescriptive (d/b) ratios, based on nominal dimensions and lateral support conditions where the member may be assumed to be stable and no reduction for C_L is needed.

- **Repetitive member factor (C_r):**

The repetitive member factor, C_r , applies only to (F_b) and to members 2 in. to 4 in. thick. ACI Committee 347, however, recommends against application of C_r for cases where base stresses have already been increased the 25% permitted for short duration loads.

3.3.3 Safety factors for accessories:

Table (13) shows recommended minimum factors of safety for formwork accessories, such as form ties, form anchors, and form hangers. In selecting these accessories, the formwork designer should be certain that materials furnished for the job meet these minimum ultimate-strength safety requirements.

3.4 Construction:

3.4.1 Contract documents:

The contract documents should set forth the tolerances required in the finished structure but should not attempt to specify the manner in which the formwork engineer/ contractor designs and builds the formwork to achieve the required tolerances.

The specification writer is encouraged to refer to this guide as a source of recommendations that can be written into the proper language for contract documents. Finish requirements for concrete surfaces should be described in measurable terms as precisely as practicable.

The layout and design of the formwork and its construction should be the responsibility of the formwork engineer/ contractor. This approach gives the necessary freedom to use skill, knowledge, and innovation to safely construct an economical structure. By reviewing the formwork drawings, the engineer/architect can understand how the formwork engineer/contractor has interpreted the contract documents. Some local areas have legal requirements defining the specific responsibilities of the engineer/architect in formwork design, review, or approval.

The contract documents should include all information about the structure necessary for the formwork engineer/contractor to design the formwork and prepare formwork drawings, such as:

1. Number, location, and details of all construction joints, contraction joints, and expansion joints that will be required for the particular job or parts of it.
2. Sequence of concrete placement, if critical.
3. Tolerances for concrete construction.
4. The live load and superimposed dead load for which the structure is designed and any live-load reduction used. This is a requirement of ACI 318.

5. Intermediate supports under stay-in-place forms, such as metal deck used for forms and permanent forms of other materials; supports, bracing, or both, required by the structural engineer's design for composite action; and any other special supports.
6. The location and order of erection and removal of shores for composite construction.
7. Special provisions essential for formwork for special construction methods and for special structures such as shells and folded plates. The basic geometry of such structures, as well as their required camber, should be given in sufficient detail to permit the formwork engineer/ contractor to build the forms.
7. Special requirements for post-tensioned concrete members. The effect of load transfer and associated movements during tensioning of post-tensioned members can be critical, and the contractor should be advised of any special provisions that should be made in the formwork for this condition.
8. Amount of required camber for slabs or other structural members to compensate for deflection of the structure. Measurements of camber attained should be made at the soffit level after initial set and before removal of formwork supports.
9. Where chamfers are required or prohibited on beam soffits or column corners.
10. Requirements for inserts, waterstops, built-in frames for openings and holes through concrete; similar requirements where the work of other trades will be attached to, supported by, or passed through formwork.
11. Where architectural features, embedded items, or the work of other trades could change the location of structural members, such as joists in one- or two-way joist systems, such changes or conditions should be coordinated by the engineer/architect.
12. Locations of and details for architectural concrete. When architectural details are to be cast into structural concrete, they should be so indicated or

referenced on the structural plans because they can play a key role in the structural design of the form.

3.4.2 An Integrated Concrete/Formwork Life Cycle:

The purpose of this section is to introduce formwork operation as an integrated part of the whole building process and to explain some of the terminology used in concrete and concrete formwork. The process of providing formwork and concrete is highly integrated.

The life cycle of formwork starts with the “choose formwork” activity. The physical activities in the formwork life cycle are represented by these steps:

- (1) Fabricate formwork.
- (2) Erect formwork.
- (3) Remove formwork.

The concrete construction life cycle starts after the “fabricate formwork” activity and ends before the “remove formwork” activity. The function of the formwork life cycle is to provide the structure with the specified shape and size, while the function of the concrete construction life cycle is to provide the structure with concrete of specified strength, durability, and surface texture. A brief description of each stage of both the concrete and formwork life cycles is given below:

1- Choose a Formwork System:

The choose formwork system activity includes the process of selecting formwork systems by analysis and design for different structural elements. It also includes the process of selecting accessories, bracing, and a release agent for the selected formwork system.

2- Fabricate Formwork:

The second step in the formwork life cycle is a fabricate formwork. This activity includes receiving formwork materials, cutting and stockpiling the materials by sizes and types, assembling the pieces into the desired shapes and sizes, and storing the forms near the lifting devices.

3- Erect Formwork, Place Inserts, and Reinforcement:

The method and sequence of erecting formwork may vary depending on the availability of lifting equipment and whether reinforcing cages are available. Forms are usually handled manually, by small derrick, or by crane. The erect formwork activity includes the process of lifting, positioning, and aligning the different formwork elements. This activity also includes the process of applying the form release agent or coating that prevents bonding of concrete to forms. The concrete life cycle starts after the erect formwork activity is finished with placing inserts and reinforcement activity. The logical sequencing of erecting formwork and its relation to placing inserts and reinforcement is:

1. Set lines a template is generally set in place on the floor slab or footing to accurately locate the column floor.
2. Erect scaffolding.
3. Install column reinforcement.
4. Provide forms for column.
5. Erect outside forms for walls.
6. Install wall reinforcement.
7. Erect inside forms for walls.
8. Install ties.
9. Provide bracing for walls.

10. Erect forms for beams.
11. Install beam reinforcement.
12. Erect forms for slabs.
13. Place inserts for mechanical and electrical connections, openings for ducts and conduits, and supporting bars for reinforcement.
14. Place secondary and main reinforcement.

4- Place Concrete:

This activity includes mixing, transporting, pumping, and placing of the concrete. The concrete used in most projects is truck-mixed. Concrete is usually transported by belt conveyers for horizontal applications, by buckets for delivery via cranes, by chutes for delivery via gravity to lower levels, and by pumping for horizontal and vertical delivery of concrete.

5- Consolidate Concrete:

Consolidation is the process of compacting or striking the concrete to mold it within the forms, around embedded inserts and reinforcement. It is also done to remove the humps and hollows. Consolidation of concrete is usually performed with hand tools or mechanical vibrators to guarantee a dense structure.

6- Finish Concrete:

This activity includes the process of treating the exposed concrete surfaces to produce the desired appearance, texture, or wearing qualities. Finishing of concrete is usually performed by moving a straight edge back and forth in a sawlike motion across the top of the concrete.

7- Cure Concrete:

The hardening of concrete is a chemical process that requires warmth and moisture. This activity involves curing concrete with water, steam, or any other method to prevent shrinkage and allow the concrete to gain sufficient

early strength. Steam curing is used where early strength gain of concrete is important. After the concrete is cured, the rest of the formwork life cycle continues with the strip forms activity. The cure concrete and strip forms activities are interchangeable depending on the type of structural element. For example, columns and walls are cured after stripping of the forms, while slabs and beams are cured before and after the forms are stripped.

8- Strip Forms:

As soon as concrete gains enough strength to eliminate immediate distress or deflection under loads resulting from its own weight and some additional loads, formwork should be stripped to allow other construction activities to start. The operation of removing the forms is called stripping or wrecking the forms. Formwork can either be partially stripped by removing small areas to prevent the slab from deflecting or completely stripped to allow the slab to deflect. As a general rule, formwork supporting members should not be removed before the strength of concrete has reached at least 70% of its design value.

9- Provide Reshores/Backshores:

Reshoring and backshoring are the processes of providing temporary vertical support shores for the stripped structural elements which have not yet developed full design strength. They also provide temporary vertical support for the completed structure after the original shoring support has been removed. Reshoring and backshoring are the two methods used to provide the concrete with support until it reaches its full design strength. This can help reduce stripping costs, which is the main advantage of reshores.

10- Remove Reshores or Backshores:

Reshores and backshores can be removed after the supported slab or member has attained sufficient strength to support all loads transferred to it. Removal of reshores or backshores must be carried out with care to avoid subjecting the structure to impact loads.

11- Repair and/or Reuse Formwork:

Reuse of concrete formwork is a key for economic formwork construction. After only five reuses, formwork materials costs drop to 40% of the initial cost. Formwork elements must be handled with care and should not be dropped. After repairing, cleaning, and oiling, the used formwork elements should either be stockpiled for future use or reused in other areas.

Before reusing formwork elements, they should be inspected for damage. Defects on the inside face must be repaired or removed; otherwise they will reflect on the finished surface of the concrete to show the same defect.

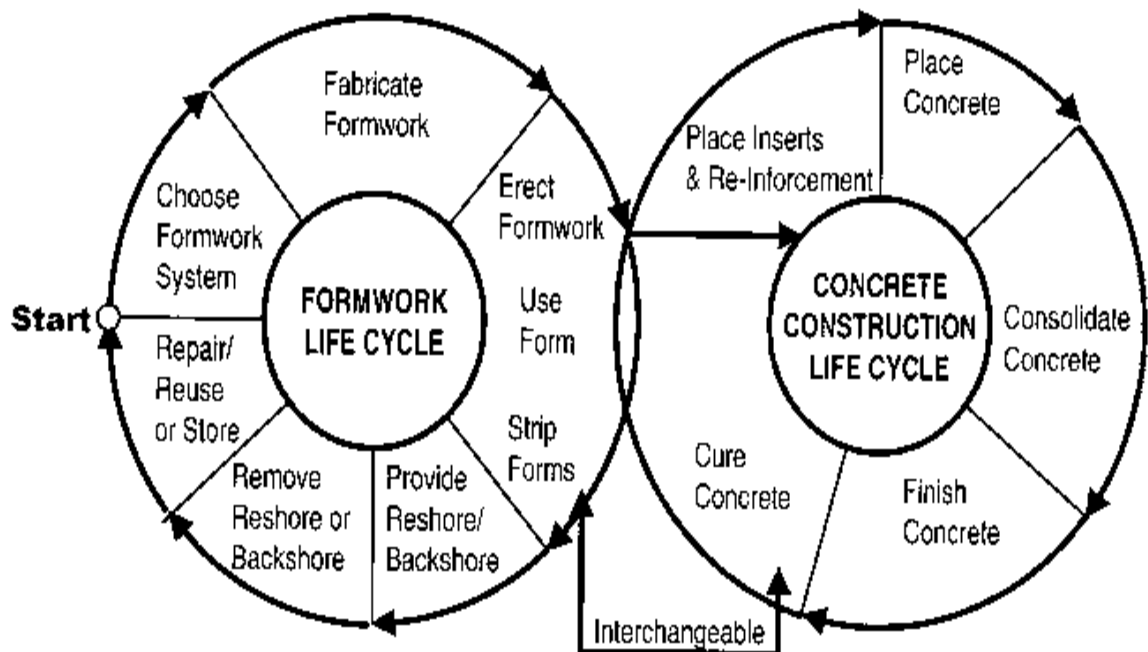


Figure (3.1): Integrated concrete formwork life cycle.

3.4.3 Construction practices and workmanship:

a- Joints in the concrete: Contraction joints, expansion joints, control joints, construction joints, and isolation joints should be installed as specified in the contract documents or as requested by the contractor and approved by the engineer/architect.

Bulkheads for joints should preferably be made by splitting the bulkhead along the lines of reinforcement passing through the bulkhead. By doing this, each portion can be positioned and removed separately. When required on the engineer/architect's plans, beveled inserts at control joints should be left undisturbed when forms are stripped and removed only after the concrete has been sufficiently cured.

b- Sloping surfaces: Sloped surfaces steeper than 1.5 horizontal to 1 vertical should be provided with a top form to hold the shape of the concrete during placement, unless it can be demonstrated that the top forms can be omitted.

c- Inspection: The inspection should be performed by a person certified as an ACI Concrete Construction Inspector or a person having equivalent formwork training and knowledge:

- I- Forms should be inspected and checked before the reinforcing steel is placed to confirm that the dimensions and the location of the concrete members will conform to the structural plans.
- II- Blockouts, inserts, sleeves, anchors, and other embedded items should be properly identified, positioned, and secured.
- III- Formwork should be checked for camber when specified in the contract documents or shown on the formwork drawings.

d- Cleanup and coatings: Forms should be thoroughly cleaned of all dirt, mortar, and foreign matter and coated with a release agent before each use. Coating can be applied by spraying, brushing, or by a roller to serve one or more of the following purposes:

- 1- Alter the texture of the contact surface.

- 2- Improve the durability of the contact surface.
- 3- Facilitate release from concrete during stripping.
- 4- Seal the contact surface from intrusion of moisture.

Form coatings should be applied before placing of reinforcing steel and should not be used in such quantities as to run onto bars or concrete construction joints.

e- Release agents: Form release agents are applied to the form contact surfaces to prevent bond and thus facilitate stripping. They can be applied permanently to form materials during manufacture or applied to the form before each use. Form release agent should not affect or react with the finished concrete in any way.

When applying in the field, be careful to avoid coating adjacent construction joint surfaces or reinforcing steel.

3.4.4 Removal of forms and supports:

Although the contractor is generally responsible for design, construction, and safety of formwork, criteria for removal of forms or shores should be specified by the engineer/architect.

The engineer/architect should specify the minimum strength of the concrete to be attained before removal of forms or shores. The strength can be determined by tests on job-cured specimens or on in-place concrete. Depending on the circumstances, a minimum elapsed time after concrete placement can be established for removal of the formwork. Determination of the time of form removal should be based on the resulting effect on the concrete.

When forms are stripped there should be no excessive deflection or distortion and no evidence of damage to the concrete due to either removal of support or to the stripping operation. Supporting forms and shores should not be removed from beams, floors, and walls until these structural units are strong enough to carry their own weight and any approved superimposed load.

As a general rule, the forms for columns and piers can be removed before forms for beams and slabs. Formwork and shoring should be constructed so each can be easily and safely removed without impact or shock and permit the concrete to carry its share of the load gradually and uniformly.

Because the minimum stripping time is a function of concrete strength, the preferred method of determining stripping time is using tests of job-cured cylinders or concrete in place. When the contract documents do not specify the minimum strength required of concrete at the time of stripping, however, the following elapsed times can be used. Shorter stripping times listed for live load to dead load ratios greater than 1.0 are the result of more reserve strength being available for dead load in absence of live load at time of stripping.

- **Time of removing formwork:**

	Time to remove
Walls*	12 h
Columns*	12 h
Sides of beams and girders*	12 h
Pan joist forms†:	
- 30 in. (760 mm) wide or less	3 days
- Over 30 in. (760 mm) wide	4 days

*Where such forms also support formwork for slab or beam soffits, the removal times of the latter should govern.

†Of the type that can be removed without disturbing forming or shoring.

- **Time of removing formwork:**

	Structural load less than structural load	live than dead	Structural live load more than structural dead load
Arch centers	14 days		7 days
Joist, beam or girder soffits:			
- Under 10 ft (3 m) clear span between structural supports	7 days‡		4 days
- 10 to 20 ft (3 to 6 m) clear span between structural supports	14 days‡		7 days
- Over 20 ft (6 m) clear span between structural supports	21 days‡		14 days
One-way floor slabs:			
- Under 10 ft (3 m) clear span between structural supports	4 days‡		3 days
- 10 to 20 ft (3 to 6 m) clear span between structural supports	7 days‡		4 days
- Over 20 ft (6 m) clear span between structural supports	10 days‡		7 days

‡Where forms can be removed without disturbing shores, use half of values shown but not less than 3 days.

3.5 Special Formwork Systems:

3.5.1 Slip forms:

Slip forms are forms that move, usually continuously, during placing of the concrete. The slip form method of concrete construction is used for forming both horizontal and vertical concrete structures. Slip-forming is like an extrusion process, with the forms acting as moving dies to shape the concrete. In wall forming, the slip form is usually moved vertically. This method can be economical when constructing concrete cores of tall buildings, tall concrete stacks, and concrete towers.

Following are typical types of concrete structures that have been constructed with the slip form method:

1. Single-cell silos.
2. Multi-cell silos.
3. Buildings.
4. Piers.
5. Towers.
6. Water reservoirs.
7. Vertical shafts for tunnels and mines.
8. Vertical shafts for missile launching bases.
9. Chimneys.

These are vertical structures, most of which have walls requiring slipforms with two surfaces to confine the concrete. However, some piers or sections of piers are solid concrete, requiring forms with external surfaces only. The concrete linings for vertical shafts are generally placed with the external surface against the natural earth or rock, requiring form linings for the inside surfaces only.

The forms for the slipform method of construction consist of the following basic parts:

1- Sheathing:

For structures that include walls with inner and outer surfaces, two sets of sheathing are required. The sheathing may be made of dressed and matched lumber or sheet steel. Steel has a longer life and a lower friction drag on the concrete than boards or plywood. The opposite faces of the sheathing should be about $\frac{1}{4}$ in. wider at the bottom than at the top, to reduce the friction and to ease the release of the concrete from the forms.

2- Wales or Ribs:

The sheathing is usually held in alignment by two rows of wales or ribs on each side. For structures with plane faces, such as buildings and piers, the wales are typically assemblies of three-ply 2×8 or 2×10 lumber planks nailed together. The end joints between lumber planks in a rib should be staggered. Steel wales are generally used with steel sheathing.

The wales serve the following purposes:

1. They support and hold the sheathing in position.
2. They support the working platform.
3. They support the suspended scaffolding.
4. They transmit the lifting forces from the yokes to the form system.
5. They act as horizontal beams between the yokes to resist the lateral pressures of the concrete.

3- Yokes:

Each yoke consists of a horizontal cross member connected to a jack, plus a yoke for each set of sheathing and wales. The top of each leg is attached to the cross member, and the lower end is attached to the bottom wale. The yokes serve two purposes. They transmit the lifting forces from the jacks to the wales. The yoke legs must also hold the sheathing in the required

positions and resist the lateral pressures of the concrete, because form ties cannot be used to maintain the required spacing between the form sheathings.

4- Working Platform:

The working platform usually consists of 1-in.-thick boards or ¾-in.-thick plywood, supported by joists. The joists may be supported at the ends only by wales, or, for long spans, they may require intermediate supports by wood or steel trusses, steel joists, or steel beams, attached to the wales. If the structure is to be finished with a concrete roof or cap, the working platform may be used as a form to support the concrete. For this purpose, pointed steel pins are driven through the sheathing into the concrete wall under the wales, and then the yokes are removed.

5- Suspended Scaffolding:

The scaffolding suspended under the forms allows finishers to have access to the concrete surfaces, which usually require some finishing. The scaffolding should be assembled on the foundation and attached to the forms by means of wire rope slings before the placement of concrete has started. Safety railings are then added to the scaffolding after concrete placement has commenced and the form is raised to provide sufficient clearance. This procedure is normally performed without the need to temporarily stop concrete placement and form lifting.

6- Form Jacks:

Jacks used to lift the forms are of three types: electric, hydraulic, and pneumatic. The jacks provide the forces required to pull the forms upward as the concrete is placed. Enough jacks must be used to lift the forms without excessive stresses on the jacks, yokes, and sections of the forms. If the jacks are overloaded, the upward movement of sections of the forms may not be uniform, which can cause distortions in the concrete structure.

These essential parts of a slip form assembly are illustrated in Figure (2.7), which is a section through a wall under construction. This form is raised by hydraulic jacks.

- **Operation of Slip forms:**

After a set of slip forms is completely assembled on a concrete base, the forms are filled slowly with concrete. When the concrete in the bottom of the forms has gained sufficient rigidity, the upward movement of the forms is started and continued at a speed that is controlled by the rate at which the concrete sets. Lifting rates may vary from 2 or 3 in. per hr to in excess of 12 in. per hr, depending on the temperature and other properties of the concrete. An experienced person should be present at all time to establish the rate of movement. The reinforcing steel is placed as the forms move upward.

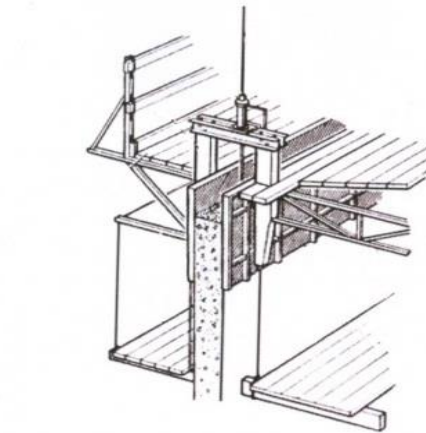


Figure (3.2-a): slip forms.

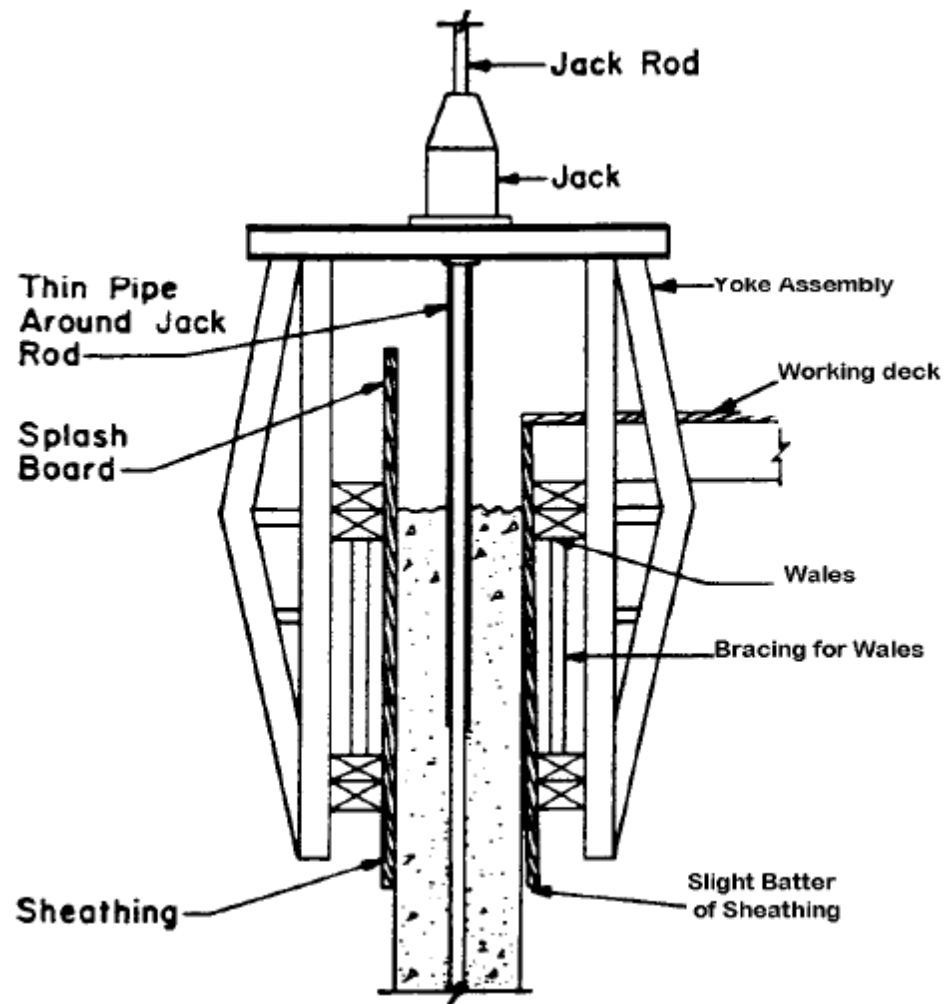


Figure (3.2-b): These essential parts of a slip form assembly are illustrated.

3.5.2 Flying Deck Forms:

The term “flying deck form” or table forms is used to designate a system of components that are assembled into units, called decks, for forming concrete slabs in multistory buildings. The same set of flying deck forms is used repeatedly to form multiple floor slabs in a building.

After the concrete that has been placed in a slab is sufficiently cured, the flying deck form for the slab is removed (without disassembly of the parts), moved (flown) horizontally outward, away from the building, and then moved up and back inward to the building to a new location, and used again to form another concrete slab. The term is derived from the process of moving (flying) the form outward, away from the building, as it is moved upward to the next floor level in the structure.

Each unit, or flying deck form, consists of various structural components, such as trusses, stringers, joists, and plywood decking. The unit is rigidly assembled to be used and reused in molding the concrete slabs of a building. The forms may be used to support concrete beams, girders, slabs, and other parts of a structure. This type of forms will be enough reuses to justify the initial cost of fabricating the forms.

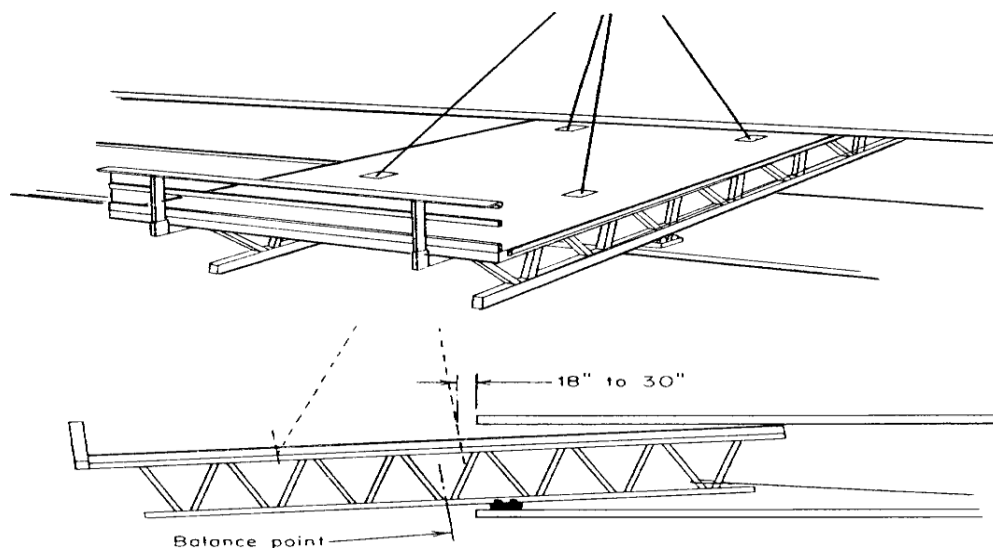


Figure (3.3): flying deck form.

3.5.3 Climbing forms:

Climbing forms or jump forms are forms that are raised vertically for succeeding lifts of concrete in a given structure, usually supported by anchors embedded in the previous lift. The form is moved only after an entire lift is placed and (partially) hardened; this should not be confused with a slip form that moves during placement of the concrete. Support of the climbing form is usually provided by anchors cast in the previous placements. It is critical that the concrete strength gain at the anchors be sufficient at each stage of the operation to resist the imposed loads.

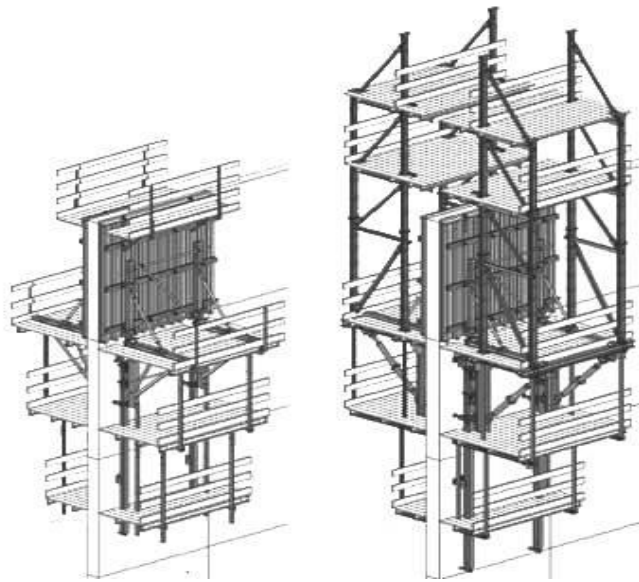


Figure (3.4): climbing forms.

3.6 Good formwork should fulfill the following criteria:

Several considerations are involved in determining an economical form construction, such as:

- 1.** Design the forms to provide the required strength with the smallest amount of materials and the most number of reuses.
- 2.** Do not specify or require a high-quality finish on concrete surfaces that will not be exposed to view by the public, such as the inside face of parapet, or walls and beams in service stairs.
- 3.** When planning forms, consider the sequence and methods of stripping them.
- 4.** Use prefabricated panels where it is possible to do so.
- 5.** Use the largest practical prefabricated panels that can be handled by the workers or equipment on the job.
- 6.** Prefabricate form members (not limited to panels) where possible. This will require planning, drawings, and detailing, but it will save money.
- 7.** Consider using patented form panels and other patented members, which frequently are less expensive than forms built entirely on the job.
- 8.** Develop standardized methods of making, erecting, and stripping forms to the maximum possible extent. Once carpenters learn these methods, they can work faster.
- 9.** When prefabricated panels and other members, such as those for foundations, columns, walls, and decking, are to be reused several times, mark or number them clearly for identification purposes.
- 10.** Use double-headed nails for temporary connections to facilitate their removal.

- 11.** Clean, oil, and renail form panels, if necessary, between reuses. Store them carefully to prevent distortion and damage.
- 12.** Use long lengths of lumber without cutting for walls, braces, stringers, and other purposes where their extending beyond the work is not objectionable. For example, there usually is no objection to letting studs extend above the sheathing on wall forms.
- 13.** Strip forms as soon as it is safe and possible to do so if they are to be reused on the structure, in order to provide the maximum number of reuses.
- 14.** Create a cost-of-materials consciousness among the carpenters who make forms. At least one contractor displayed short boards around his project on which the cost was prominently displayed.
- 15.** Conduct jobsite analyses and studies to evaluate the fabrication, erection, and removal of formwork. Such studies may reveal methods of increasing productivity rates and reducing costs.

3.7 Safety precautions:

Contractors should follow all state, local, and federal codes, ordinances, and regulations pertaining to forming and shoring. In addition to the very real moral and legal responsibility to maintain safe conditions for workmen and the public, safe construction is, in the final analysis, more economical than any short-term cost savings from cutting corners on safety provisions.

Attention to safety is particularly significant in formwork construction that supports the concrete during its plastic state and until the concrete becomes structurally self-sufficient. Following the design criteria contained in this guide is essential for ensuring safe performance of the forms. All structural members and connections should be carefully planned so that a sound determination of loads may be accurately made and stresses calculated.

In addition to the adequacy of the formwork, special structures, such as multistory buildings, require consideration of the behavior of newly completed beams and slabs that are used to support formwork and other construction loads. It should be kept in mind that the strength of freshly cast slabs or beams is less than that of a mature slab.

Formwork failures can be attributed to substandard materials and equipment, human error, and inadequacy in design. Careful supervision and continuous inspection of formwork during erection, concrete placement, and removal can prevent many accidents.

Construction procedures should be planned in advance to ensure the safety of personnel and the integrity of the finished structure. Some of the safety provisions that should be considered are:

Below is a partial list of rules that can be used to reduce the potential of formwork failures:

1. Prepare a formwork plan that includes detailed drawings and written specifications for fabricating, erecting, and dismantling of the formwork. The plan should be prepared by a person who is competent in the design of formwork.
2. Follow all state, local, and federal codes, ordinances, and regulations pertaining to formwork, shoring, and scaffolding.
3. Post guidelines for shoring and scaffolding in a conspicuous place and ensure that all persons who erect, dismantle, or use shoring are aware of them.
4. Ensure compliance of all OSHA rules and regulations.
5. Follow all instructions, procedures, and recommendations from manufacturers of formwork components used in the formwork.
6. Provision for adequate illumination of the formwork and work area.
7. Survey the jobsite for hazards, such as loose earth fills, ditches, debris, overhead wires, and unguarded openings.
8. Ensure adequate fall protection for workers during erection of formwork, pouring of concrete, and dismantling of formwork.

- 9.** Inspect all shoring and scaffolding before using it, to ensure it is in proper working condition and to ensure workers are using the equipment properly.
- 10.** Make a thorough check of the formwork system after it is erected and immediately before a pour, in particular connections between formwork components.
- 11.** Inclusion of lifting points in the design and detailing of all forms that will be crane-handled. This is especially important in flying forms or climbing forms. In the case of wall formwork, consideration should be given to an independent work platform bolted to the previous lift.
- 12.** Incorporation of provisions for anchorage of alternative fall protection devices, such as personal fall arrest systems, safety net systems, and positioning device systems.
- 13.** A program of field safety inspections of formwork.
- 14.** Never take chances. If in doubt regarding the safety, contact a safety officer and management. It is best to prevent an accident.