Guide to Formwork for Concrete

An ACI Standard

Reported by ACI Committee 347

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Objectives of safety, quality, and economy are given priority in these guidelines for formwork. A section on contract documents explains the kind and amount of specification guidance the engineer/architect should provide for the contractor. The remainder of the report advises the formwork engineer/contractor on the best ways to meet the specification requirements safely and economically. Separate chapters deal with design, construction, and materials for formwork. Considerations peculiar to architectural concrete are also outlined in a separate chapter. Other sections are devoted to formwork for bridges, shells, mass concrete, and underground work. The concluding chapter on formwork for special methods of construction includes slipforming, preplaced-aggregate concrete, tremie concrete, precast, and prestressed concrete.

Keywords: anchors; architectural concrete; coatings; concrete; construction; falsework; form ties; forms; formwork; foundations; quality control; reshoring; shoring; slipform construction; specifications; tolerances.

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PREFACE

Before the formation of ACI Committee 347 (formerly ACI Committee 622) in 1955, there had been an increase in the use of reinforced concrete for longer span structures, multistoried structures, and increased story heights.

The need for a formwork standard and increased knowledge concerning the behavior of formwork was evident from the rising number of failures, sometimes resulting in the loss of life. The first report by the committee, based on a survey of current practices in the United States and Canada, was published in the ACI JOURNAL in June 1957.[1.1] The second committee report was published in the ACI JOURNAL in August 1958.[1.2] This second report was an in-depth review of test reports and design formulas for determining lateral pressure on vertical formwork. The major result of this study and report was the development of a basic formula establishing form pressures to be used in the design of vertical formwork.

The first standard was ACI 347-63. Subsequent revisions were ACI 347-68 and ACI 347-78. Two subsequent revisions, ACI 347R-88 and ACI 347R-94, were committee reports because of changes in the ACI policy on the style and format of standards. ACI 347-01 returned the guide to the standardization process.

A major contribution of the committee has been the sponsorship and review of *Formwork for Concrete*[1.3] by M. K. Hurd, first published in 1963 and currently in its sixth edition. Now comprising more than 490 pages, this is the most comprehensive and widely used document on this subject. (The Japan National Council on Concrete has published a Japanese translation.)

The paired values stated in inch-pound and SI units are usually not exact equivalents. Therefore, each system is to be used independently of the other. Combining values from the two systems may result in nonconformance with this document.

CHAPTER 1—INTRODUCTION

1.1—Scope

This guide covers:

- A listing of information to be included in the contract documents;
- Design criteria for horizontal and vertical forces on formwork;
- Design considerations, including safety factors, to be used in determining the capacities of formwork accessories;
- Preparation of formwork drawings;
- Construction and use of formwork, including safety considerations;
- Materials for formwork;
- Formwork for special structures;
- Formwork for special methods of construction; and
- Qualification of personnel for inspection and testing.

This guide is based on the premise that layout, design, and construction of formwork should be the responsibility of the formwork engineer/contractor. This is believed to be fundamental to the achievement of safety and economy of formwork for concrete.

1.2—Definitions

The following definitions will be used in this guide. Many of the terms can also be found in ACI 116R:

backshores—shores placed snugly under a concrete slab or structural member after the original formwork and shores have been removed from a small area at a time, without allowing the slab or member to deflect; thus, the slab or other member does not yet support its own weight or existing construction loads from above.

bugholes—surface air voids: small regular or irregular cavities, usually less than 0.6 in. (15 mm) in diameter, resulting from entrapment of air bubbles in the surface of formed concrete during placement and consolidation. Also called blowholes.

centering—specialized temporary support used in the construction of arches, shells, and space structures where the entire temporary support is lowered (struck or decentered) as a unit to avoid introduction of injurious stresses in any part of the structure.

climbing form—a form that is raised vertically for succeeding lifts of concrete in a given structure.

diagonal bracing—supplementary formwork members designed to resist lateral loads.

engineer/architect—the engineer, architect, engineering firm, architectural firm, or other agency issuing project plans and specifications for the permanent structure, administering the work under contract documents, or both.

flying forms—large prefabricated, mechanically handled sections of formwork designed for multiple reuse; frequently including supporting truss, beam, or shoring assemblies completely unitized. Note: Historically, the term has been applied to floor forming systems.

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

formwork—total system of support for freshly placed concrete, including the mold or sheathing that contacts the concrete and all supporting members, hardware, and necessary bracing.

formwork engineer/contractor—engineer of the formwork system, contractor, or competent person in charge of designated aspects of formwork design and formwork operations.

ganged forms—large assemblies used for forming vertical surfaces; also called gang forms.

horizontal lacing—horizontal bracing members attached to shores to reduce their unsupported length, thereby increasing load capacity and stability.

preshores—added shores placed snugly under selected panels of a deck-forming system before any primary (original) shores are removed. Preshores and the panels they support remain in place until the remainder of the complete bay has been stripped and backshored, a small area at a time.

reshores—shores placed snugly under a stripped concrete slab or other structural member after the original forms and shores have been removed from a large area, requiring the new slab or structural member to deflect and support its own weight and existing construction loads to be applied before installation of the reshores.

scaffold—a temporary elevated platform (supported or suspended) and its supporting structure used for supporting workers, tools, and materials; adjustable metal scaffolding can be used for shoring in concrete work, provided its structure has the necessary load-carrying capacity and structural integrity.

shores—vertical or inclined support members designed to carry the weight of the formwork, concrete, and construction loads above.

slipform—a form that is pulled or raised as concrete is placed; may move in a horizontal direction to lay concrete for concrete paving or on slopes and inverts of canals, tunnels, and siphons; or may move vertically to form walls, bins, or silos.

1.3—Achieving economy in formwork

The engineer/architect can help overall economy in the structure by planning so that formwork costs are minimized. The cost of formwork in the United States can be as much as 60% of the total cost of the completed concrete structure in place and sometimes greater. This investment requires careful thought and planning by the engineer/architect when designing and specifying the structure and by the formwork engineer/contractor when designing and constructing the formwork.

Formwork drawings, prepared by the formwork engineer/contractor, can identify potential problems and should give project site employees a clear picture of what is required and how to achieve it. The following guidelines show how the engineer/architect can plan the structure so that formwork economy may best be achieved:

- To simplify and permit maximum reuse of formwork, the dimensions of footings, columns, and beams should be of standard material multiples, and the number of sizes should be minimized;
- When interior columns are the same width as or smaller than the girders they support, the column form becomes a simple rectangular or square box without boxouts, and the slab form does not have to be cut out at each corner of the column;
- When all beams are made one depth (beams framing into beams as well as beams framing into columns), the supporting structures for the beam forms can be carried on a level platform supported on shores;
- Considering available sizes of dressed lumber, plywood, and other ready-made formwork components and keeping beam and joist sizes constant will reduce labor time;
- The design of the structure should be based on the use of one standard depth wherever possible when commercially available forming systems, such as one- or two-way joist systems, are used;
- The structural design should be prepared simultaneously with the architectural design so that dimensions can be better coordinated. Room sizes can vary a few inches to accommodate the structural design;
- The engineer/architect should consider architectural features, depressions, and openings for mechanical or electrical work when detailing the structural system, with the aim of achieving economy. Variations in the structural system caused by such items should be shown on the structural plans. Wherever possible, depressions in the tops of slabs should be made without a corresponding break in elevations of the soffits of slabs, beams, or joists;
- Embedments for attachment to or penetration through the concrete structure should be designed to minimize random penetration of the formed surface; and
- Avoid locating columns or walls, even for a few floors, where they would interfere with the use of large formwork shoring units in otherwise clear bays.

1.4—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 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.

1.4.1 *Individual specifications*—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.

The specification for formwork will affect the overall economy and quality of the finished work; therefore, it should be tailored for each particular job, clearly indicate what is expected of the contractor, and ensure economy and safety.

A well-written formwork specification tends to equalize bids for the work. Unnecessarily exacting requirements can make bidders question the specification as a whole and make it difficult for them to understand exactly what is expected. They can be overly cautious and overbid or misinterpret requirements and underbid.

A well-written formwork specification is of value not only to the owner and the contractor, but also to the field representative of the engineer/architect, approving agency, and the subcontractors of other trades. Some requirements can be written to allow discretion of the contractor where quality of finished concrete work would not be impaired by the use of alternative materials and methods.

Consideration of the applicable general requirements suggested herein will not be sufficient to make a complete specification. Requirements should be added for actual materials, finishes, and other items peculiar to and necessary for the individual structure. The engineer/architect can exclude, call special attention to, strengthen, or make more lenient any general requirement to best fit the needs of the particular project. Helpful and detailed information is given in *Formwork for Concrete*.[1.3]

1.4.2 *Formwork materials and accessories*—If the particular design or desired finish requires special attention, the engineer/architect can specify in the contract documents the formwork materials and such other features necessary to attain the objectives. If the engineer/architect does not call for specific materials or accessories, the formwork engineer/contractor can choose any materials that meet the contract requirements.

When structural design is based on the use of commercially available form units in standard sizes, such as one-way or two-way joist systems, plans should be drawn to make use of available shapes and sizes. Some latitude should be permitted for connections of form units to other framing or centering to reflect the tolerances and normal installation practices of the form type anticipated.

1.4.3 *Finish of exposed concrete*—Finish requirements for concrete surfaces should be described in measurable terms as precisely as practicable. Refer to Section 3.4 and Chapter 5.

1.4.4 *Design, inspection, review, and approval of formwork*—Although the safety of formwork is the responsibility of the contractor, the engineer/architect or approving agency may, under certain circumstances, decide to review and approve the formwork, including drawings and calculations. If so, the engineer/architect should call for such review or approval in the contract documents.

Approval might be required for unusually complicated structures, structures whose designs were based on a particular method of construction, structures in which the forms impart a desired architectural finish, certain post-tensioned structures, folded plates, thin shells, or long-span roof structures.

The following items should be clarified in the contract documents:

- Who will design the formwork;
- Who will inspect the specific feature of formwork and when will the inspection be performed; and
- What reviews, approvals, or both will be required—
  a. For formwork drawings;
  b. For the formwork before concreting and during concreting; and
  c. Who will give such reviews, approvals, or both.

1.4.5 *Contract documents*—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:

- 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;
- Sequence of concrete placement, if critical;
- Tolerances for concrete construction;
- 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;
- 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;
- The location and order of erection and removal of shores for composite construction;
- 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;
- 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;
- 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;
- Where chamfers are required or prohibited on beam soffits or column corners;
- Requirements for inserts, waterstops, built-in frames for openings and holes through concrete; similar requirements where the work of other trades will be

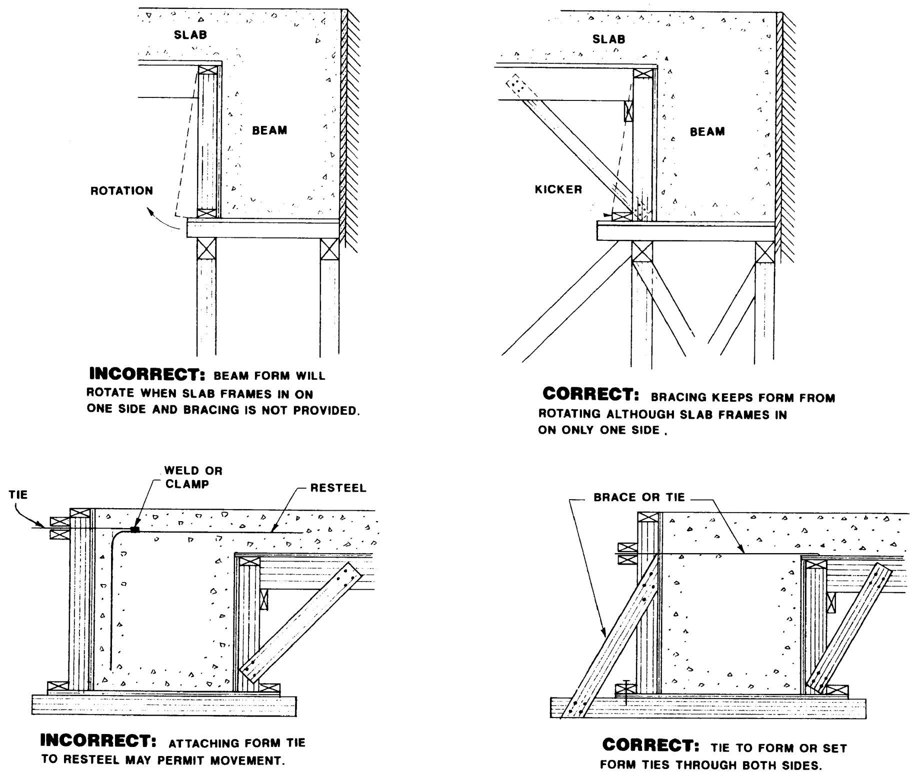

Fig. 2.1—Prevention of rotation is important where the slab frames into the beam form on only one side.

attached to, supported by, or passed through formwork;

- 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; and
- 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.

CHAPTER 2—DESIGN

2.1—General

2.1.1 *Planning*—All formwork should be well planned before construction begins. The amount of planning required will depend on the size, complexity, and importance (considering reuses) of the form. Formwork should be designed for strength and serviceability. System stability and member buckling should be investigated in all cases.

2.1.2 *Design methods*—Formwork is made of many different materials, and the commonly used design practices for each material are to be followed (refer to Chapter 4). For example, wood forms are designed by working-stress methods recommended by the American Forest and Paper Association. When the concrete structure becomes a part of the formwork support system, as in many multistory buildings, it is important for the formwork engineer/contractor to recognize that the concrete structure has been designed by the strength method. Accordingly, in communication of the loads, it should be clear whether they are service loads or factored loads.

Throughout this guide, the terms design, design load, and design capacity are used to refer to design of the formwork. Where reference is made to design load for the permanent structure, structural design load, structural dead load, or some similar term is used to refer to unfactored service loads on the structure.*

2.1.3 *Basic objectives*—Formwork should be designed so that concrete slabs, walls, and other members will have the correct dimensions, shape, alignment, elevation, and position within established tolerances. Formwork should also be designed 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. 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. Responsibility for the design of the formwork rests with the contractor or the formwork engineer hired by the contractor to design and be responsible for the formwork.

2.1.4 *Design deficiencies*—Some common design deficiencies that can lead to failure are:

- Lack of allowance in design for loadings such as wind, power buggies, placing equipment, and temporary material storage;
- Inadequate reshoring;
- Overstressed reshoring;
- Inadequate provisions to prevent rotation of beam forms where the slabs frame into them on only one side (Fig. 2.1);
- Insufficient anchorage against uplift due to battered form faces;

*As defined by ACI 318, both dead load and live load are unfactored loads.

- Insufficient allowance for eccentric loading due to placement sequences;
- Failure to investigate bearing stresses in members in contact with shores or struts;
- Failure to provide proper lateral bracing or lacing of shoring;
- Failure to investigate the slenderness ratio of compression members;
- Inadequate provisions to tie corners of intersecting cantilevered forms together;
- Failure to account for loads imposed on form hardware anchorages during closure of form panel gaps when aligning formwork; and
- Failure to account for elastic shortening during post-tensioning.

2.1.5 *Formwork drawings and calculations*—Before constructing forms, the formwork engineer/contractor may be required to submit detailed drawings, design calculations, or both of proposed formwork for review and approval by the engineer/architect or approving agency. If such drawings are not approved by the engineer/architect or approving agency, the formwork engineer/contractor should make such changes as may be required before the start of construction of the formwork.

The review, approval, or both of the formwork drawings does not relieve the contractor of the responsibility for adequately constructing and maintaining the forms so that they will function properly. If reviewed by persons other than those employed by the contractor, the review or approval indicates that no exception is taken by the reviewer to the assumed design loadings in combination with design stresses shown; the proposed construction methods; the placement rates, equipment, and sequences; the proposed form materials; and the overall scheme of formwork. All major design values and loading conditions should be shown on formwork drawings. These include assumed values of live load; the compressive strength of concrete for formwork removal and for application of construction loads; rate of placement, minimum temperature, height, and drop of concrete; weight of moving equipment that can be operated on formwork; foundation pressure; design stresses; camber diagrams; and other pertinent information, if applicable.

In addition to specifying types of materials, sizes, lengths, and connection details, formwork drawings should provide for applicable details, such as:

- Procedures, sequence, and criteria for removal of forms, shores, and reshores;
- Design allowance for construction loads on new slabs when such allowance will affect the development of shoring, reshoring schemes, or both (refer to Sections 2.5 and 3.8 for shoring and reshoring of multistory structures);
- Anchors, form ties, shores, lateral bracing, and horizontal lacing;
- Field adjustment of forms;
- Waterstops, keyways, and inserts;
- Working scaffolds and runways;
- Weepholes or vibrator holes, where required;
- Screeds and grade strips;
- Location of external vibrator mountings;
- Crush plates or wrecking plates where stripping can damage concrete;
- Removal of spreaders or temporary blocking;
- Cleanout holes and inspection openings;
- Construction joints, contraction joints, and expansion joints in accordance with contract documents (also refer to ACI 301);
- Sequence of concrete placement and minimum elapsed time between adjacent placements;
- Chamfer strips or grade strips for exposed corners and construction joints;
- Camber;
- Mudsills or other foundation provisions for formwork;
- Special provisions, such as safety, fire, drainage, and protection from ice and debris at water crossings;
- Formwork coatings;
- Notes to formwork erector showing size and location of conduits and pipes projecting through formwork; and
- Temporary openings or attachments for climbing crane or other material handling equipment.

2.2—Loads

2.2.1 *Vertical loads*—Vertical loads consist of dead and live loads. The weight of formwork plus 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. Refer to Section 2.5.

The formwork should be designed for a live load of not less than 50 lb/ft^2 (2.4 kPa) of horizontal projection. When motorized carts are used, the live load should not be less than 75 lb/ft^2 (3.6 kPa).

The design load for combined dead and live loads should not be less than 100 lb/ft^2 (4.8 kPa) or 125 lb/ft^2 (6.0 kPa) if motorized carts are used.

2.2.2 *Lateral pressure of concrete*—Unless the conditions of Section 2.2.2.1 or 2.2.2.2 are met, formwork should be designed for the lateral pressure of the newly placed concrete given in Eq. (2.1a) or (2.1b). Minimum values given for other pressure formulas do not apply to Eq. (2.1a) and (2.1b).

$$p = wh \text{ (lb/ft}^2\text{)} \qquad (2.1a)$$

$$p = \rho gh \text{ (kPa)} \qquad (2.1b)$$

where

p = lateral pressure, lb/ft^2 (kPa);
w = unit weight of concrete, lb/ft^3;
ρ = density of concrete, kg/m^3;
g = gravitational constant, 9.81 N/kg; and
h = depth of fluid or plastic concrete from top of placement to point of consideration in form, ft (m).

The set characteristics of a mixture should be understood, and using the rate of placement, the level of fluid concrete

Table 2.1—Unit weight coefficient C_w

Inch-pound version		SI version	
Unit weight of concrete	C_w	Density of concrete	C_w
Less than 140 lb/ft^3	$C_w = 0.5[1 + (w/145\ lb/ft^3)]$ but not less than 0.80	Less than 2240 kg/m^3	$C_w = 0.5[1 + (w/2320\ kg/m^3)]$ but not less than 0.80
140 to 150 lb/ft^3	1.0	2240 to 2400 kN/m^3	1.0
More than 150 lb/ft^3	$C_w = w/145\ lb/ft^3$	More than 2400 kg/m^3	$C_w = w/2320\ kg/m^3$

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. (2.1a) [(2.1b)] should be used until the effect on formwork pressure is understood by measurement.

2.2.2.1 *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, where p_{max} = maximum lateral pressure, lb/ft^2; R = rate of placement, ft/h; T = temperature of concrete during placing, °F; C_w = unit weight coefficient per Table 2.1; and C_c = chemistry coefficient per Table 2.2.[2.1]

For columns:

$$p_{max} = C_w C_c[150 + 9000R/T] \quad (2.2)$$

with a minimum of $600C_w$ 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

$$p_{max} = C_w C_c[150 + 9000R/T] \quad (2.3)$$

with a minimum of $600C_w$ 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

$$p_{max} = C_w C_c[150 + 43{,}400/T + 2800R/T] \quad (2.4)$$

with a minimum of $600C_w$ lb/ft^2, but in no case greater than wh.

2.2.2.1 *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, where p_{max} = maximum lateral pressure, kPa; R = rate of placement, m/h; T = temperature of concrete during placing, °C; C_w = unit weight coefficient per Table 2.1; and C_c = chemistry coefficient per Table 2.2.[2.1]

For columns

Table 2.2—Chemistry coefficient C_c

Cement type or blend	C_c
Types I, II, and III without retarders*	1.0
Types I, II, and III with a retarder	1.2
Other types or blends containing less than 70% slag or 40% fly ash without retarders*	1.2
Other types or blends containing less than 70% slag or 40% fly ash with a retarder*	1.4
Blends containing more than 70% slag or 40% fly ash	1.4

*Retarders include any admixture, such as a retarder, retarding water reducer, retarding midrange water-reducing admixture, or high-range water-reducing admixture (superplasticizer), that delays setting of concrete.

$$p_{max} = C_w C_c\left[7.2 + \frac{785R}{T + 17.8}\right] \quad (2.2)$$

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

For walls with a rate of placement of less than 2.1 m/h and a placement height not exceeding 4.2 m

$$p_{max} = C_w C_c\left[7.2 + \frac{785R}{T + 17.8}\right] \quad (2.3)$$

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

For walls 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

$$p_{max} = C_w C_c\left[7.2 + \frac{1156}{T + 17.8} + \frac{244R}{T + 17.8}\right] \quad (2.4)$$

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

2.2.2.1.1—The unit weight coefficient C_w is determined from Table 2.1.

2.2.2.1.2—The chemistry coefficient C_c is determined from Table 2.2.

2.2.2.1.3—For the purpose of applying the pressure formulas, columns are defined as vertical elements with no plan dimension exceeding 6.5 ft (2 m). Walls are defined as vertical elements with at least one plan dimension greater than 6.5 ft (2 m).

2.2.2.2—Alternatively, a method based on appropriate experimental data can be used to determine the lateral pressure used for form design (References 2.2 to 2.7).

Table 2.3—Minimum safety factors of formwork accessories*

Accessory	Safety factor	Type of construction
Form tie	2.0	All applications
Form anchor	2.0	Formwork supporting form weight and concrete pressures only
	3.0	Formwork supporting weight of forms, concrete, construction live loads, and impact
Form hangers	2.0	All applications
Anchoring inserts used as form ties	2.0	Precast-concrete panels when used as formwork

*Safety factors are based on the ultimate strength of the accessory when new.

2.2.2.3—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.

2.2.2.4—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.

2.2.2.5—For slipform lateral pressures, refer to Section 7.3.2.4.

2.2.3 *Horizontal loads*—Braces and shores should be designed to resist all horizontal loads such as wind, cable tensions, inclined supports, dumping of concrete, and starting and stopping of equipment. Wind loads on enclosures or other wind breaks attached to the formwork should be considered in addition to these loads.

2.2.3.1—For building construction, the assumed value of horizontal load due to wind, dumping of concrete, inclined placement of concrete, and equipment acting in any direction at each floor line should be not less than 100 lb/linear ft (1.5 kN/m) of floor edge or 2% of total dead load on the form distributed as a uniform load per linear foot (meter) of slab edge, whichever is greater.

2.2.3.2—Wall form bracing should be designed to meet the minimum wind load requirements of the local building code or ANSI/SEI/ASCE-7 with adjustment for shorter recurrence interval as provided in SEI/ASCE 37. For wall forms exposed to the elements, the minimum wind design load should be not less than 15 lb/ft^2 (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.

2.2.3.3—Wall forms of unusual height or exposure should be given special consideration.

2.2.4 *Special loads*—The formwork should be designed for any special conditions of construction likely to occur, such as unsymmetrical placement of concrete, impact of machine-delivered concrete, uplift, concentrated loads of reinforcement, form handling loads, and storage of construction materials. Form designers should provide for special loading conditions, such as walls constructed over spans of slabs or beams that exert a different loading pattern before hardening of concrete than that for which the supporting structure is designed.

Imposition of any construction loads on the partially completed structure should not be allowed, except as specified in formwork drawings or with the approval of the engineer/architect. Refer to Section 3.8 for special conditions pertaining to multistory work.

2.2.5 *Post-tensioning loads*—Shores, reshores, and backshores need to be analyzed for both concrete placement loads and for all load transfer that takes place during post-tensioning.

2.3—Unit stresses

Unit stresses for use in the design of formwork, exclusive of accessories, are given in the applicable codes or specifications listed in Chapter 4. When fabricated formwork, shoring, or scaffolding units are used, manufacturer's recommendations for allowable loads can be followed if supported by engineering calculations, test reports of a qualified and recognized testing agency, or successful experience records. For formwork materials that will experience substantial reuse, reduced values should be used. For formwork materials with limited reuse, allowable stresses specified in the appropriate design codes or specifications for temporary structures or for temporary loads on permanent structures can be used. Where there will be a considerable number of formwork reuses or where formwork is fabricated from materials such as steel, aluminum, or magnesium, the formwork should be designed as a permanent structure carrying permanent loads.

2.4—Safety factors for accessories

Table 2.3 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.

2.5—Shores

Shores and reshores or backshores (as defined in Section 1.2) should be designed to carry all loads transmitted to them. A rational analysis should be used to determine the number of floors to be shored, reshored, or backshored and to determine the loads transmitted to the floors, shores, and reshores or backshores as a result of the construction sequence.

The analysis should consider, but should not necessarily be limited to:

- Structural design load of the slab or member including live load, partition loads, and other loads for which the engineer of the permanent structure designed the slab. Where the engineer included a reduced live load for the design of certain members and allowances for construction loads, such values should be shown on the structural plans and be taken into consideration when performing this analysis;
- Dead load weight of the concrete and formwork;
- Construction live loads, such as placing crews and equipment or stored materials;

- Design strength of specified concrete;
- Cycle time between the placement of successive floors;
- Strength of concrete at the time it is required to support shoring loads from above;
- The distribution of loads between floors, shores, and reshores or backshores at the time of placing concrete, stripping formwork, and removal of reshoring or backshoring;[1.3, 2.8, 2.9, 2.10]
- Span of slab or structural member between permanent supports;
- Type of formwork systems, that is, span of horizontal formwork components, and individual shore loads; and
- Minimum age of concrete where appropriate.

Commercially available load cells can be placed under selected shores to monitor actual shore loads to guide the shoring and reshoring during construction.[2.11]

Field-constructed butt or lap splices of timber shoring are not recommended unless they are made with fabricated hardware devices of demonstrated strength and stability. If plywood or lumber splices are made for timber shoring, they should be designed to prevent buckling and bending of the shoring.

Before construction, an overall plan for scheduling of shoring and reshoring or backshoring, and calculation of loads transferred to the structure, should be prepared by a qualified and experienced formwork designer. The structure's capacity to carry these loads should be reviewed or approved by the engineer/architect. The plan and responsibility for its execution remain with the contractor.

2.6—Bracing and lacing

The formwork system should be designed to transfer all horizontal loads to the ground or to completed construction in such a manner as to ensure safety at all times. Diagonal bracing should be provided in vertical and horizontal planes where required to resist lateral loads and to prevent instability of individual members. Horizontal lacing can be considered in design to hold in place and increase the buckling strength of individual shores and reshores or backshores. Lacing should be provided in whatever directions are necessary to produce the correct slenderness ratio l/r for the load supported, where l = unsupported length and r = least radius of gyration. The braced system should be anchored to ensure stability of the total system.

2.7—Foundations for formwork

Proper foundations on ground, such as mudsills, spread footings, or pile footings, should be provided. If soil under mudsills is or may become incapable of supporting superimposed loads without appreciable settlement, it should be stabilized or other means of support should be provided. No concrete should be placed on formwork supported on frozen ground.

2.8—Settlement

Formwork should be designed and constructed so that vertical adjustments can be made to compensate for take-up and settlements.

CHAPTER 3—CONSTRUCTION

3.1—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:

- Erection of safety signs and barricades to keep unauthorized personnel clear of areas in which erection, concrete placing, or stripping is under way;
- Providing experienced form watchers during concrete placement to ensure early recognition of possible form displacement or failure. A supply of extra shores or other material and equipment that might be needed in an emergency should be readily available;
- Provision for adequate illumination of the formwork and work area;
- 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;
- Incorporation of scaffolds, working platforms, and guardrails into formwork design and all formwork drawings;
- Incorporation of provisions for anchorage of alternative fall protection devices, such as personal fall arrest systems, safety net systems, and positioning device systems; and
- A program of field safety inspections of formwork.

3.1.1 *Formwork construction deficiencies*—Some common construction deficiencies that can lead to formwork failures are:

- Failure to inspect formwork during and after concrete

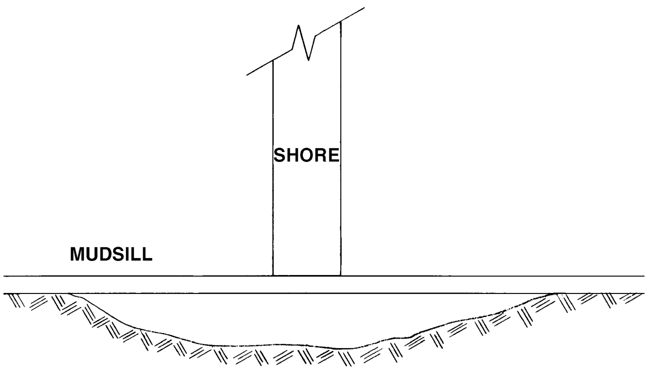

Fig. 3.1—Inadequate bearing under mudsill.

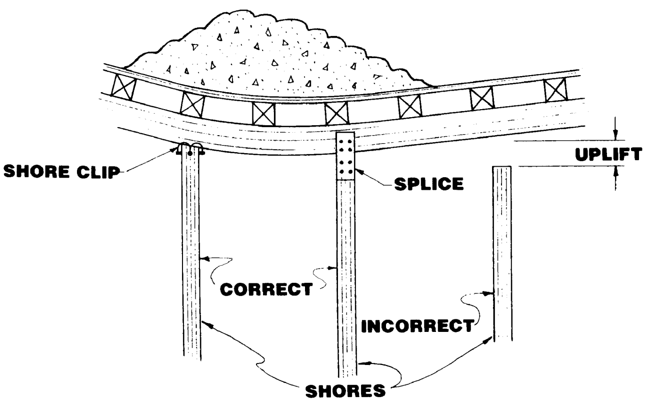

Fig. 3.2—Uplift of formwork. Connection of shores to joists and stringers should hold shores in place when uplift or torsion occurs. Lacing to reduce the shore slenderness ratio can be required in both directions.

placement to detect abnormal deflections or other signs of imminent failure that could be corrected;
- Insufficient nailing, bolting, welding, or fastening;
- Insufficient or improper lateral bracing;
- Failure to comply with manufacturer's recommendations;
- Failure to construct formwork in accordance with the form drawings;
- Lack of proper field inspection by qualified persons to ensure that form design has been properly interpreted by form builders; and
- Use of damaged or inferior lumber having lower strength than needed.

3.1.1.1 *Examples of deficiencies in vertical formwork*—Construction deficiencies sometimes found in vertical formwork include:
- Failure to control rate of placing concrete vertically without regard to design parameters;
- Inadequately tightened or secured form ties or hardware;
- Form damage in excavations resulting from embankment failure;
- Use of external vibrators on forms not designed for their use;
- Deep vibrator penetration of earlier semihardened lifts;
- Improper framing of blockouts;
- Improperly located or constructed pouring pockets;
- Inadequate bulkheads;
- Improperly anchored top forms on a sloping face;
- Failure to provide adequate support for lateral pressures on formwork; and
- Failure to provide adequate bracing resulting in attempts to plumb forms against concrete pressure force.

3.1.1.2 *Examples of deficiencies in horizontal formwork*—Construction deficiencies sometimes found in horizontal forms for elevated structures include:
- Failure to properly regulate the rate and sequence of placing concrete horizontally to avoid unanticipated loadings on the formwork;
- Shoring not plumb, thus inducing lateral loading and reducing vertical load capacity;
- Locking devices on metal shoring not locked, inoperative, or missing. Safety nails missing on adjustable two-piece wood shores;
- Failure to account for vibration from adjacent moving loads or load carriers;
- Inadequately tightened or secured shore hardware or wedges;
- Loosening or premature removal of reshores or backshores under floors below;
- Premature removal of supports, especially under cantilevered sections;
- Inadequate bearing area or unsuitable soil under mudsills (Fig. 3.1);
- Mudsills placed on frozen ground subject to thawing;
- Connection of shores to joists, stringers, or wales that are inadequate to resist uplift or torsion at joints (refer to Fig. 3.2);
- Failure to consider effects of load transfer that can occur during post-tensioning (refer to Section 3.8.7); and
- Inadequate shoring and bracing of composite construction.

3.2—Construction practices and workmanship

3.2.1—*Fabrication and assembly details*

3.2.1.1—Studs, wales, or shores should be properly spliced.

3.2.1.2—Joints or splices in sheathing, plywood panels, and bracing should be staggered.

3.2.1.3—Shores should be installed plumb and with adequate bearing and bracing.

3.2.1.4—Specified size and capacity of form ties or clamps should be used.

3.2.1.5—All form ties or clamps should be installed and properly tightened as specified. All threads should fully engage the nut or coupling. A double nut may be required to develop the full capacity of the tie.

3.2.1.6—Forms should be sufficiently tight to prevent loss of mortar from the concrete.

3.2.1.7—Access holes may be necessary in wall forms or other high, narrow forms to facilitate concrete placement.

3.2.2—*Joints in the concrete*

3.2.2.1—Contraction joints, expansion joints, control joints, construction joints, and isolation joints should be installed as specified in the contract documents (refer to Fig. 3.3) or as requested by the contractor and approved by the engineer/architect.

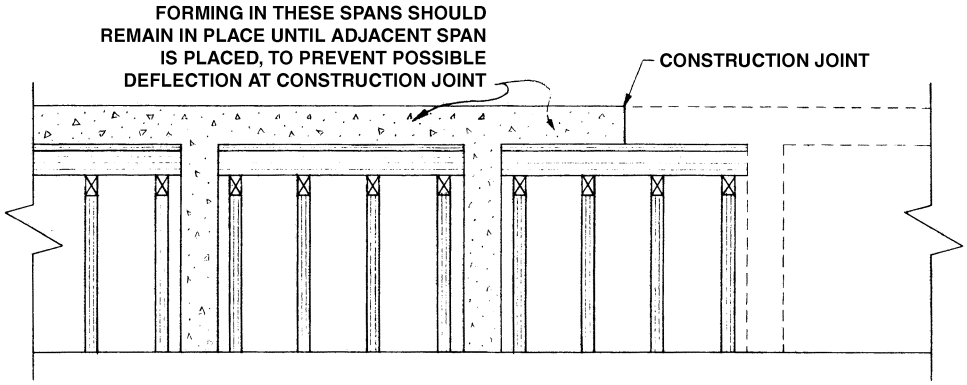

Fig. 3.3—Forming and shoring restraints at construction joints in supported slabs.

3.2.2.2—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. Wood strips inserted for architectural treatment should be kerfed to permit swelling without causing pressure on the concrete.

3.2.3 *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.

3.2.4 *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.

3.2.4.1—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.

3.2.4.2—Blockouts, inserts, sleeves, anchors, and other embedded items should be properly identified, positioned, and secured.

3.2.4.3—Formwork should be checked for camber when specified in the contract documents or shown on the formwork drawings.

3.2.5—*Cleanup and coatings*

3.2.5.1—Forms should be thoroughly cleaned of all dirt, mortar, and foreign matter and coated with a release agent before each use. Where the bottom of the form is inaccessible from within, access panels should be provided to permit thorough removal of extraneous material before placing concrete. If surface appearance is important, forms should not be reused if damage from previous use would cause impairment to concrete surfaces.

3.2.5.2—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.

3.2.6—*Construction operations on the formwork*

3.2.6.1—Building materials, including concrete, should not be dropped or piled on the formwork in such a manner as to damage or overload it.

3.2.6.2—Runways for moving equipment should be provided with struts or legs as required and should be supported directly on the formwork or structural member. They should not bear on or be supported by the reinforcing steel unless special bar supports are provided. The formwork should be suitable for the support of such runways without significant deflections, vibrations, or lateral movements.

3.2.7 *Loading new slabs*—Overloading of new slabs by temporary material stockpiling or by early application of permanent loads should be avoided. Loads, such as aggregate, lumber, reinforcing steel, masonry, or machinery should not be placed on new construction in such a manner as to damage or overload it.

3.3—Tolerances

Tolerance is a permissible variation from lines, grades, or dimensions given in contract documents. Suggested tolerances for concrete structures can be found in ACI 117.

The contractor should set and maintain concrete forms, including any specified camber, to ensure completed work is within the tolerance limits.

3.3.1 *Recommendations for engineer/architect and contractor*—Tolerances should be specified by the engineer/architect so that the contractor will know precisely what is required and can design and maintain the formwork accordingly. Specifying tolerances more exacting than needed can increase construction costs.

Contractors should be required to establish and maintain control points and benchmarks in an undisturbed condition until final completion and acceptance of a project. Both should be adequate for the contractor's use and for reference to establish tolerances. This requirement can become even more important for the contractor's protection when tolerances are not specified or shown. The engineer/architect should specify tolerances or require performance appropriate to the type of construction. Specifying tolerances more stringent than commonly obtained for a specific type of construction should be avoided, as this usually results in disputes among the parties involved. For example, specifying permitted irregularities more stringent than those allowed for a Class C surface (Table 3.1) is incompatible with most concrete one-way joist construction techniques. Where a project involves features sensitive to the cumulative effect of tolerances on

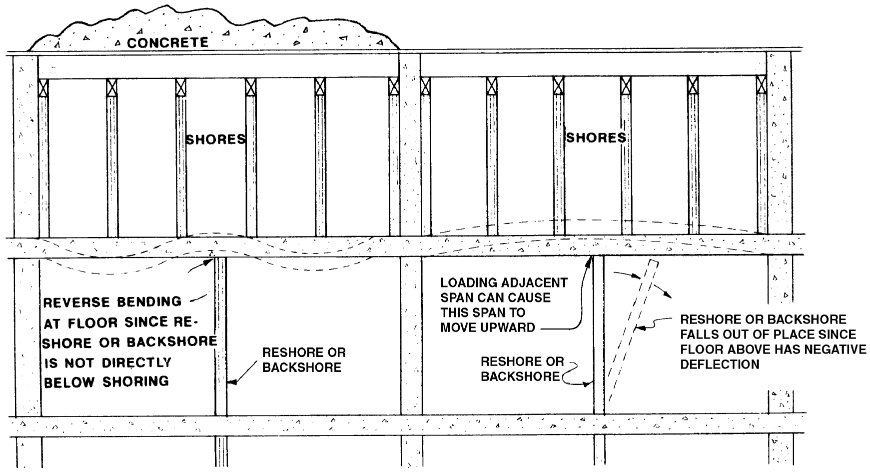

Fig. 3.4—Reshore installation. Improper positioning of shore from floor to floor can create bending stresses for which the slab was not designed.

Table 3.1—Permitted abrupt or gradual irregularities in formed surfaces as measured within a 5 ft (1.5 m) length with a straightedge

Class of surface			
A	B	C	D
1/8 in. (3 mm)	1/4 in. (6 mm)	1/2 in. (13 mm)	1 in. (25 mm)

individual portions, the engineer/architect should anticipate and provide for this effect by setting a cumulative tolerance. Where a particular situation involves several types of generally accepted tolerances on items such as concrete, location of reinforcement, and fabrication of reinforcement, which become mutually incompatible, the engineer/architect should anticipate the difficulty and specify special tolerances or indicate that governs. The project specifications should clearly state that a permitted variation in one part of the construction or in one section of the specifications should not be construed as permitting violation of the more stringent requirements for any other part of the construction or in any other such specification section.

The engineer/architect should be responsible for coordinating the tolerances for concrete work with the tolerance requirements of other trades whose work adjoins the concrete construction. For example, the connection detail for a building's façade should accommodate the tolerance range for the lateral alignment and elevation of the perimeter concrete member.

3.4—Irregularities in formed surfaces

This section provides a way of evaluating surface variations due to forming quality but is not intended for evaluation of surface defects, such as bugholes (blowholes) and honeycomb, attributable to placing and consolidation deficiencies. The latter are more fully explained by ACI 309.2R. Allowable irregularities are designated either abrupt or gradual. Offsets and fins resulting from displaced, mismatched, or misplaced forms, sheathing, or liners, or from defects in forming materials are considered abrupt irregularities. Irregularities resulting from warping and similar uniform variations from planeness or true curvature are considered gradual irregularities.

Gradual irregularities should be checked with a straightedge for plane surfaces or a shaped template for curved or warped surfaces. In measuring irregularities, the straightedge or template can be placed anywhere on the surface in any direction.

Four classes of formed surface are defined in Table 3.1. The engineer/architect should indicate which class is required for the work being specified or indicate other irregularity limits where needed, or the concrete surface tolerances as specified in ACI 301 should be followed.

Class A is suggested for surfaces prominently exposed to public view where appearance is of special importance. Class B is intended for coarse-textured, concrete-formed surfaces intended to receive plaster, stucco, or wainscoting. Class C is a general standard for permanently exposed surfaces where other finishes are not specified. Class D is a minimum-quality requirement for surfaces where roughness is not objectionable, usually applied where surfaces will be permanently concealed. Special limits on irregularities can be needed for surfaces continuously exposed to flowing water, drainage, or exposure. If permitted irregularities are different from those given in Table 3.1, they should be specified by the engineer/architect.

3.5—Shoring and centering

3.5.1 *Shoring*—Shoring should be supported on satisfactory foundations, such as spread footings, mudsills, or piling, as discussed in Section 2.7.

Shoring resting on intermediate slabs or other construction already in place need not be located directly above shores or reshores below, unless the slab thickness and the location of its reinforcement are inadequate to take the reversal of stresses and punching shear. The reversal of stresses results from the reversal of bending moments in the slab over the shore or reshore below as shown in Fig. 3.4. Where the conditions are questionable, the shoring location should be approved by the engineer/architect. If reshores do not align with the shores above, then calculate for reversal stresses. Generally, the dead load stresses are sufficient to compensate for reversal stresses caused by reshores. Reshores should be prevented from falling.

All members should be straight and true without twists or bends. Special attention should be given to beam and slab or one- and two-way joist construction to prevent local overloading when a heavily loaded shore rests on the thin slab.

Multitier shoring, single-post shoring in two or more tiers, is a dangerous practice and is not recommended.

Where a slab load is supported on one side of the beam only (refer to Fig. 2.1), edge beam forms should be carefully planned to prevent tipping of the beam due to unequal loading.

Vertical shores should be erected so that they cannot tilt and should have a firm bearing. Inclined shores should be braced securely against slipping or sliding. The bearing ends of shores should be square. Connections of shore heads to other framing should be adequate to prevent the shores from falling out when reversed bending causes upward deflection of the forms (refer to Fig. 3.2).

3.5.2 *Centering*—When centering is used, lowering is generally accomplished by the use of sand boxes, jacks, or wedges beneath the supporting members. For the special problems associated with the construction of centering for folded plates, thin shells, and long-span roof structures, refer to Section 6.4.

3.5.3 *Shoring for composite action between previously erected steel or concrete framing and cast-in-place concrete*—Refer to Section 6.3.

3.6—Inspection and adjustment of formwork

Helpful information about forms before, during, and after concreting can be found in Reference 1.3 and ACI 311.1R.

3.6.1—*Before concreting*

3.6.1.1—Telltale devices should be installed on shores or forms to detect formwork movements during concreting.

3.6.1.2—Wedges used for final alignment before concrete placement should be secured in position before the final check.

3.6.1.3—Formwork should be anchored to the shores below so that movement of any part of the formwork system will be prevented during concreting.

3.6.1.4—Additional elevation of formwork should be provided to allow for closure of form joints, settlements of mudsills, shrinkage of lumber, and elastic shortening and dead load deflections of form members.

3.6.1.5—Positive means of adjustment (wedges or jacks) should be provided to permit realignment or readjustment of shores if settlement occurs.

3.6.2 *During and after concreting*—During and after concreting, but before initial set of the concrete, the elevations, camber, and plumbness of formwork systems should be checked using telltale devices.

Formwork should be continuously watched so that any corrective measures found necessary can be promptly made. Form watchers should always work under safe conditions and establish in advance a method of communication with placing crews in case of emergency.

3.7—Removal of forms and supports

3.7.1 *Discussion*—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.

3.7.2—*Recommendations*

3.7.2.1—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. Other concrete tests or procedures (refer to ACI 228.1R) can be used such as the maturity method, rebound numbers, penetration resistance, or pullout tests, but these methods should be correlated to the actual concrete mixture used in the project, periodically verified by job-cured specimens, and approved by the engineer/architect. The engineer/architect should specify who will make the specimens and who will make the tests. Results of such tests, as well as records of weather conditions and other pertinent information, should be recorded by the contractor. 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 (Fig. 3.5). When forms are removed before the specified curing is completed, measures should be taken to continue the curing and provide adequate thermal protection for the concrete. 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. In no case should supporting forms and shores be removed from horizontal members before the concrete has achieved the strength specified by the engineer/architect.

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.

3.7.2.2—The removal of forms, supports, and protective enclosures, and the discontinuance of heating and curing should follow the requirements of the contract documents. When standard beam or cylinder tests are used to determine stripping times, test specimens should be cured under conditions that are not more favorable than the most unfavorable conditions for the concrete the test specimens represent. The curing records can serve as the basis on which the engineer/architect will determine the review or approval of form stripping.

3.7.2.3—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

*Helpful information on strength development of concrete under varying conditions of temperature and with various admixtures can be found in ACI 305R and ACI 306R.

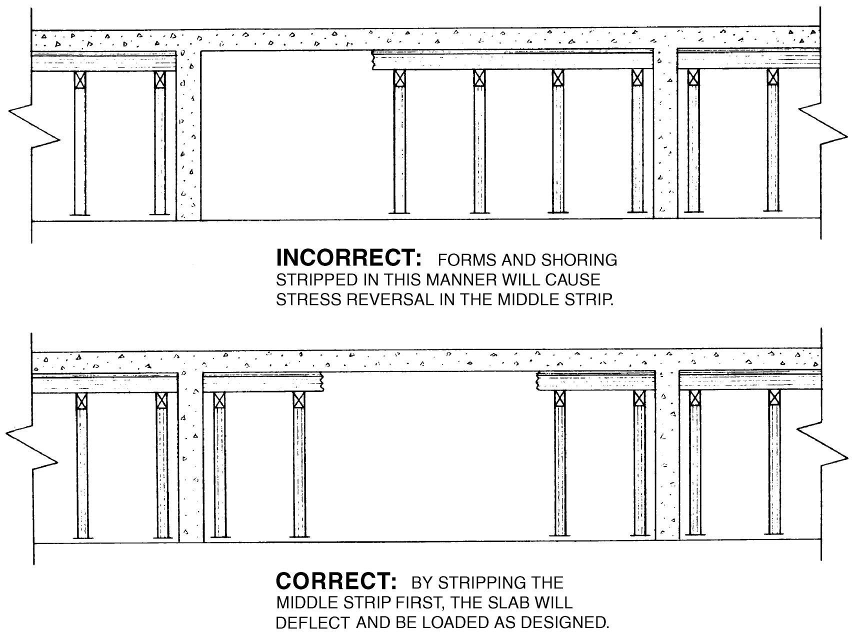

Fig. 3.5—Stripping sequence for two-way slabs.

specify the minimum strength required of concrete at the time of stripping, however, the following elapsed times can be used. The times shown represent a cumulative number of days, or hours, not necessarily consecutive, during which the temperature of the air surrounding the concrete is above 50 °F (10 °C). If high early-strength concrete is used, these periods can be reduced as approved by the engineer/architect. Conversely, if ambient temperatures remain below 50 °F (10 °C), or if retarding agents are used, then these periods should be increased at the discretion of the engineer/architect. 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.

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

	Structural live load less than structural dead load	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

Two-way slab systems[§]........Removal times are contingent on reshores where required, being placed as soon as practicable after stripping operations are complete but not later than the end of the working day in which stripping occurs. Where reshores are required to implement early stripping while minimizing sag or creep (rather than for distribution of superimposed construction loads as covered in Section 3.8), capacity and spacing of such reshores should be designed by the formwork engineer/contractor and reviewed by the engineer/architect.

Post-tensioned slab system[§]........As soon as full post-tensioning has been applied.

3.8—Shoring and reshoring of multistory structures

3.8.1 *Discussion*—The following definitions apply for purposes of this discussion:

shores—vertical or inclined support members designed to carry the weight of formwork, concrete, and construction loads.

reshores—shores placed snugly under a stripped concrete slab or structural member after the original forms and shores have been removed from a large area. This requires the new

[*]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.

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

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

[§]Refer to Section 3.8 for special conditions affecting number of floors to remain shored or reshored.

slab or structural member to deflect and support its own weight and existing construction loads applied before the installation of the reshores. It is assumed that the reshores carry no load at the time of installation. Afterward, additional construction loads will be distributed among all members connected by reshores.

Multistory work represents special conditions, particularly in relation to the removal of forms and shores. Reuse of form material and shores is an obvious economy. Furthermore, the speed of construction in this type of work permits other trades to follow concreting operations from floor to floor as closely as possible. The shoring that supports freshly placed and low-strength early-age concrete, however, is supported by lower floors that were not originally designed specifically for these loads. The loads imposed must not exceed the safe capacity of each floor providing support. For this reason, shoring or reshoring should be provided for a sufficient number of floors to distribute the imposed construction loads to several slab levels without causing excessive stresses, excessive slab deflections, or both.[1.3,2.8,2.9,2.10] Reshoring is used to distribute construction loads to the lower floors.

In a common method of analysis, while reshoring remains in place at grade level, each level of reshores carries the weight of only the new slab plus other construction live loads. The weight of intermediate slabs is not included because each slab carries its own weight before reshores are put in place.

Once the tier of reshores in contact with grade has been removed, the assumption is made that the system of slabs behaves elastically. The slabs interconnected by reshores will deflect, equally during addition or removal of loads. Loads will be distributed among the slabs in proportion to their developed stiffness. The deflection of concrete slabs can be considered elastic, that is, neglecting shrinkage and creep. Caution should also be taken when a wood compressible system is used. Such systems tend to shift most of the imposed construction loads to the upper floors, which have less strength. Addition or removal of loads may be due to construction activity or to removing shores or reshores in the system. Shore loads are determined by equilibrium of forces at each floor level.

3.8.2 *Advantages of reshoring*—Stripping formwork is more economical if all the material can be removed at the same time and moved from the area before placing reshores. Slabs are allowed to support their own weight, reducing the load in the reshores. Combination of shores and reshores usually requires fewer levels of interconnected slabs, thus freeing more areas for other trades.

3.8.3 *Other methods*—Other methods of supporting new construction are less widely used and involve leaving the original shores in place or replacing them individually (backshoring and preshoring), which prevents the slab from deflecting and carrying its own weight. These methods are not recommended unless performed under careful supervision by the formwork engineer/contractor and with review by the engineer/architect because excessively high slab and shore stresses can develop.

3.8.4 *Design*—Refer to Chapter 2.

3.8.5 *Placing reshores*—When used in this section, the word shore refers to either reshores or the original shores.

Reshoring is one of the most critical operations in formwork; consequently, the procedure should be planned in advance by the formwork engineer/contractor and should be reviewed or approved by the engineer/architect. Operations should be performed so that areas of new construction will not be required to support combined dead and construction loads in excess of their capability, as determined by design load and developed concrete strength at the time of stripping and reshoring.

Shores should not be located so as to alter the pattern of stress determined in the structural analysis or induce tensile stresses where reinforcing bars are not provided. Size and number of shores, and bracing, if required, should provide a supporting system capable of carrying any loads that could be imposed on it.

Where possible, shores should be located in the same position on each floor so that they will be continuous in their support from floor to floor. When shores above are not directly over shores below, an analysis should be made to determine whether or not detrimental stresses are produced in the slab. This condition seldom occurs in reshoring because the bending stresses normally caused by the offset reshores are not large enough to overcome the stress resulting from the slab carrying its own dead load. Where slabs are designed for light live loads or on long spans where the loads on the shores are heavy, care should be used in placing the shores so that the loads on the shores do not cause excessive punching shear or bending stress in the slab.

While reshoring is under way, no construction loads should be permitted on the new construction unless the new construction can safely support the construction loads.

When placing reshores, care should be taken not to preload the lower floor and not to remove the normal deflection of the slab above. The reshore is simply a strut and should be tightened only to the extent necessary to achieve good bearing contact without transferring load between upper and lower floors.

3.8.6 *Removal of reshoring*—Shores should not be removed until the supported slab or member has attained sufficient strength to support itself and all applied loads. Removal operations should be carried out in accordance with a planned sequence so that the structure supported is not subject to impact or loading eccentricities.

3.8.7 *Post-tensioning effects on shoring and reshoring*—The design and placement of shores and reshores for post-tensioned construction requires more consideration than for normal reinforced concrete. The stressing of post-tensioning tendons can cause overloads to occur in shores, reshores, or other temporary supports. The stressing sequence has the greatest effect. When a slab is post-tensioned, the force in the tendon produces a downward load at the beam. If the beam is shored, the shoring should carry this added load. The magnitude of the load can approach the dead load of 1/2 the slab span on both sides of the beam. If the floor slab is tensioned before the supporting beams and girders, a careful analysis of the load transfer to the beam or girder shores or reshores will be required.

Similar load transfer situations occur in post-tensioned bridge construction.

CHAPTER 4—MATERIALS

4.1—General

The selection of materials suitable for formwork should be based on the price, safety during construction, and the quality required in the finished product. Approval of formwork materials by the engineer/architect, if required by the contract documents, should be based on how the quality of materials affects the quality of finished work. Where the concrete surface appearance is critical, the engineer/architect should give special notice and make provision for preconstruction mock-ups. Refer to Chapter 5 for architectural concrete provisions.

4.2—Properties of materials

4.2.1 *General—Formwork for Concrete*[1.3] describes the formwork materials commonly used in the United States and provides extensive related data for form design. Useful specification and design information is also available from manufacturers and suppliers. Table 4.1 indicates specific sources of design and specification data for formwork materials.

This tabulated information should not be interpreted to exclude the use of any other materials that can meet quality and safety requirements established for the finished work.

4.2.2 *Sheathing*—Sheathing is the supporting layer of formwork closest to the concrete. It can be in direct contact with the concrete or separated from it by a form liner. Sheathing consists of wood, plywood, metal, or other materials capable of transferring the load of the concrete to supporting members, such as joists or studs. Liners are made of wood, plastic, metal, cloth, or other materials selected to alter or enhance the surface of the finished concrete.

In selecting and using sheathing and lining materials, important considerations are:

- Strength;
- Stiffness;
- Release;
- Reuse and cost per use;
- Surface characteristics imparted to the concrete, such as wood grain transfer, decorative patterns, gloss, or paintability;
- Absorptiveness or ability to drain excess water from the concrete surface;
- Resistance to mechanical damage, such as from vibrators and abrasion from slipforming;
- Workability for cutting, drilling, and attaching fasteners;
- Adaptability to weather and extreme field conditions, temperature, and moisture; and
- Weight and ease of handling.

4.2.3 *Structural supports*—Structural support systems carry the dead and live loads that have been transferred through the sheathing. Important considerations are:

- Strength;
- Stiffness;
- Dimensional accuracy and stability;
- Workability for cutting, drilling, and attaching fasteners;
- Weight;
- Cost and durability; and
- Flexibility to accommodate varied contours and shapes.

4.3—Accessories

4.3.1 *Form ties*—A form tie is a tensile unit used to hold concrete forms against the active pressure of freshly placed plastic concrete. In general, it consists of an inside tensile member and an external holding device, both made to specifications of various manufacturers. These manufacturers also publish recommended working loads on the ties for use in form design. There are two basic types of tie rods: the one-piece prefabricated rod or band type and the threaded internal disconnecting type. Their suggested working loads range from 1000 to more than 50,000 lb (4.4 to more than 220 kN).

4.3.2 *Form anchors*—Form anchors are devices used to secure formwork to previously placed concrete of adequate strength. The devices normally are embedded in the concrete during placement. The actual load-carrying capacity of the anchors depends on their shape and material, the strength and type of concrete in which they are embedded, the area of contact between concrete and anchor, and the depth of embedment and location in the member. Manufacturers publish design data and test information to assist in the selection of proper form anchor devices.

4.3.3 *Form hangers*—Form hangers are devices used to suspend formwork loads from structural steel, precast concrete, or other members.

4.3.4 *Side form spacers*—A side form spacer is a device that maintains the desired distance between a vertical form and reinforcing bars. Both factory-made and job-site fabricated devices have been successfully used. Advantages and disadvantages of the several types are explained in References 1.3, 4.1, and 4.2.

4.3.5—*Recommendations*

4.3.5.1—The recommended factors of safety for ties, anchors, and hangers are given in Section 2.4.

4.3.5.2—The rod- or band-type form tie, with a supplemental provision for spreading the forms and a holding device engaging the exterior of the form, is the common type used for light construction.

The threaded internal disconnecting type of tie (also called through tie) is more often used for formwork on heavy construction, such as heavy foundations, bridges, power houses, locks, dams, and architectural concrete.

Removable portions of all ties should be of a type that can be readily removed without damage to the concrete and that leaves the smallest practicable holes to be filled. Removable portions of the tie should be removed unless the contract documents permit their remaining in place.

A minimum specification for form ties should require that the bearing area of external holding devices be adequate to prevent excessive bearing stress in form lumber.

4.3.5.3—Form hangers should support the dead load of forms, weight of concrete, and construction and impact loads. Form hangers should be symmetrically arranged on the supporting member and loaded, through proper sequencing of

Table 4.1—Form materials with data sources for design and specification

Materials	Principal uses	Data sources
Sawn lumber	Form framing, sheathing, and shoring	"American Softwood Lumber Standard," *PS 20-94* *Wood Handbook*, Reference 4.3 *Manual for Wood Frame Construction*, Reference 4.4 *National Design Specification for Wood Construction*, ANSI/AF&PA NDS-1997, Reference 4.7 *Timber Construction Manual*, Reference 4.6 *Structural Design in Wood*, Reference 4.5
Engineered wood*	Form framing and shoring	*Engineered Wood Products*, Reference 4.21 "Code for Engineering Design in Wood," (Canada) *CAN3-086* "Engineering Design in Wood (Limit States Design)," *CAN/CSA-096.1-94*
Plywood	Form sheathing and panels	"Construction and Industrial Plywood," *PSI-95* APA *Plywood Design Specification*, Reference 4.8 APA *Concrete Forming*, Reference 4.20
Steel	Panel framing and bracing Heavy forms and falsework	*Specification for Structural Steel Buildings—Allowable Stress Design and Plastic Design*, Reference 4.9 *Specification for Design of Cold Formed Steel Structural Members*, Reference 4.10
	Column and joist forms	*Forms for One-Way Joist Construction,* ANSI A48.1 *Forms for Two-Way Concrete Joist Construction*, ANSI A48.2 *Recommended Industry Practice for Concrete Joist Construction*, part of Reference 4.1
	Stay-in-place deck forms	ASTM A 446 (galvanized steel)
	Shoring	*Recommended Safety Requirements for Shoring Concrete Formwork*, Reference 4.19
	Steel joists used as horizontal shoring	*Recommended Horizontal Shoring Beam Erection Procedure*, Reference 4.18
	Expanded metal bulkheads, single-sided forms	*Standard Specification and Load Tables for Open Web Steel Joists*, Reference 4.17 *Expand Your Forming Options*, Reference 4.16
Aluminum†	Form panels and form framing members Horizontal and vertical shoring and bracing	*Aluminum Construction Manual,* Reference 4.11
Reconstituted wood panel products‡	Form liners and sheathing	*Mat Formed Wood Particle Board*, ANSI A208.1 *Hardboard Concrete Form Liners*, LLB-810a *Performance Standard for Wood-Based Structural Use Panels,* PS2-92
Insulation materials • Wood fiber or glass fiber • Other commercial products	Stay-in-place form liners or sheathing Cold-weather protection for fresh concrete	ASTM C 532 (insulating form board)
Fiber or laminated paper pressed tubes or forms	Column and beam forms Void forms for slabs, beams, girders and precast piles	
Corrugated cardboard	Internal and under-slab void forms Void forms in beams and girders (normally used with internal "egg-crate" stiffeners)	*A Study of Cardboard Voids for Prestressed Concrete Box Slabs*, Reference 4.12

Note: Manufacturers' recommendations, when supported by test data and field experience, are a primary source for many form materials. In addition, the handbooks, standards, specifications, and other data sources cited herein are listed in more detail in *Formwork for Concrete* and in the references for Chapter 4 and Chapter 8 of this document. Be sure to check cautionary footnotes for engineered wood, aluminum, and panel products made of reconstituted wood.

*Structural composite lumber products are proprietary and unique to a particular manufacturer. They cannot be interchanged because industry-wide common grades have not been established to serve as a basis for equivalence.

†Should be readily weldable and protected against galvanic action at the point of contact with steel. If used as a facing material in contact with fresh concrete, should be nonreactive to concrete or concrete containing calcium chloride.

‡Check surface reaction with wet concrete.

Table 4.1 (cont.)—Form materials with data sources for design and specification

Materials	Principal uses	Data sources
Concrete	Stay-in-place forms Molds for precast units	*Building Code Requirements for Structural Concrete and Commentary,* ACI 318 *Precast Concrete Units Used as Form for Cast-in-Place Concrete*, ACI 347.1R
Glass fiber-reinforced plastic	Ready-made column forms Domes and pans for concrete joist construction Custom-made forms for special architectural effects Form ties	*Using Glass-Fiber Reinforced Forms,* Reference 4.13 *Nonmetallic Form Ties*, Reference 4.14
Cellular plastics	Form lining and insulation Stay-in-place wall forms	*Cellular Plastics in Construction*, Reference 4.15 Insulating Concrete Forms Association
Other plastics, including ABS, polypropylene, polyethylene, polyvinyl chloride, polyurethane	Form liners, both rigid and flexible, for decorative concrete Chamfer and rustication formers	*Plastic Form Liners*, Reference 4.22
Rubber and rubberized or architectural fabrics	Form lining and void forms Inflatable forms for dome and culvert construction	Monolithic Dome Institute
Form ties, anchors, and hangers	Hold formwork secure against loads and pressures from concrete and construction activities	Safety factors recommended in Section 2.4 Also refer to Reference 4.14
Side form spacers	Maintain correct distance between reinforcement and form to provide specified concrete cover for steel	*Side Form Spacers*, Reference 4.2
Plaster	Waste molds for architectural concrete	
Release agents and protective form coatings	Help preserve form facing and facilitate release	*Choosing and Using a Form Release Agent*, Reference 4.23

Note: Manufacturers' recommendations, when supported by test data and field experience, are a primary source for many form materials. In addition, the handbooks, standards, specifications, and other data sources cited herein are listed in more detail in *Formwork for Concrete* and in the references for Chapter 4 and Chapter 8 of this document. Be sure to check cautionary footnotes for engineered wood, aluminum, and panel products made of reconstituted wood.

the concrete placement, to minimize twisting or rotation of the hanger or supporting members. Form hangers should closely fit the flange or bearing surface of the supporting member so that applied loads are transmitted properly.

4.3.5.4—Where the concrete surface is exposed and appearance is important, the proper type of form tie or hanger will not leave exposed metal at the surface. Otherwise, noncorrosive materials should be used when tie holes are left unpatched, exposing the tie to the elements.

4.4—Form coatings and release agents

4.4.1 *Coatings*—Form coatings or sealers are usually applied in liquid form to contact surfaces either during manufacture or in the field to serve one or more of the following purposes:

- Alter the texture of the contact surface;
- Improve the durability of the contact surface;
- Facilitate release from concrete during stripping; or
- Seal the contact surface from intrusion of moisture.

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

4.4.3 *Manufacturers' recommendations*—Manufacturers' recommendations should be followed in the use of coatings, sealers, and release agents, but independent investigation of their performance is recommended before use. When concrete surface color is critical, effects of the coating, sealing, and release agents should be evaluated. Where surface treatments such as paint, tile adhesive, sealers, or other coatings are to be applied to formed concrete surfaces, be sure that adhesion of such surface treatments will not be impaired or prevented by use of the coating, sealers, or release agent. Also, consider bonding requirements of subsequent concrete placements.

CHAPTER 5—ARCHITECTURAL CONCRETE

5.1—Introduction

5.1.1 *Objective*—The general requirements for formwork presented in preceding chapters for the most part also apply to architectural concrete. Additional information is available in ACI 301 and ACI 303R.

This chapter identifies and emphasizes additional factors that can have a critical influence on formwork for cast-in-place architectural concrete. Tilt-up and precast architectural concrete are not considered here. Concrete receiving coatings or plasters that hide the surface color and texture is not considered architectural.

5.1.2 *Definition*—ACI Committee 303 defines architectural concrete as concrete that is exposed as an interior or exterior surface in the completed structure, contributes to its visual character, and is specifically designated as such in the contract documents. Particular care should be taken in the selection of materials, design, and construction of the formwork, and placing and consolidation of the concrete to eliminate bulges, offsets, or other unsightly features in the finished surface and to maintain the integrity of the surface texture or configuration. The character of the concrete surface to be produced should also be considered when the form materials are selected. Special attention should be given to closure techniques, concealment of joints in formwork materials, and to the sealing of forms to make them watertight.

5.1.3 *Factors in addition to formwork*—Many factors other than formwork affect the architectural effects achieved in concrete surfaces. They start at the design stage and carry through to the completed project. Factors affecting the concrete can also include the mixture proportions or aggregate, the method of placing the concrete, the consolidation technique, and the curing procedure. Chemicals can have an effect on the final product, whether used as additives in the mixture; applied directly to the concrete, such as curing compounds; or applied indirectly, such as form release agents. Even after the structure is completed, weather and air pollution will affect the appearance of the concrete. These and other influencing factors should be identified and their effects evaluated during the initial design stages. The single most important factor for the success of an architectural concrete job is good workmanship.

5.1.4 *Uniform construction procedures*—Architectural concrete should have a uniform color and surface finish. The best way for the contractor to achieve this uniformity is to be consistent in all construction practices. Forming materials should be kept the same, and release agents should be applied uniformly and consistently. Placement and consolidation of the concrete should be standardized so that uniform density is achieved. Stripping and curing sequences should be kept constant throughout the work to control color variations.

5.2—Role of the architect

5.2.1 *Preplanning*—Much architectural concrete is also structural, but surface quality generally desired for architectural concrete is higher than what is typically satisfactory for structural concrete, and is more costly. The architect can use the latest information available in the art of forming and concrete technology during the design process to keep plans in line with the budget for the structure. However, intricacies and irregularities can raise the budget to a point that outweighs the architectural concrete's aesthetic contributions. The architect can make form reuse possible by standardizing building elements, such as columns, beams, and windows, and by making uninterrupted form areas the same size wherever possible to facilitate the use of standard form gangs or modules. The increased size of these uninterrupted areas will contribute to forming economy. A prebid conference with qualified contractors will bring out many practical considerations before the design is finalized.

5.2.2 *Contract documents and advance approvals*—The architect should prepare contract documents that fully instruct the bidder as to the location and desired appearance of architectural surfaces, as well as other specific requirements listed in Sections 5.2.3 to 5.2.7. On major work, this is frequently achieved by specifying a preconstruction mockup prepared and finished by the contractor for approval by the architect, using proposed form materials, jointing techniques, and form surface treatments, such as wetting, oiling, or lacquering. Once such a mockup has been completed to the satisfaction of the architect, it remains at the site for the duration of the work as a standard with which the rest of the work should comply.

Design reference samples, which are smaller specimens of concrete with the proposed surface appearance, may also be created for approval by the architect. Small samples like these, kept at the job site for reference, are not as good as a full-scale mockup but can be helpful. The samples should be large enough to adequately represent the surface of the concrete. If the samples are to be used as a basis for acceptance, several should be made to represent the variation that can occur in the finish.

In the absence of physical mockups or reference samples, it can be helpful to specify viewing conditions under which the concrete surfaces will be evaluated for compliance with the specifications.

5.2.3 *Tolerances*—The architect should specify dimensional tolerances considered essential to successful execution of the design. ACI 117 can be consulted, but the architect should realize that the tolerances therein are for concrete construction in general, and more restrictive tolerances can be required for architectural work. No numerical limits are suggested herein because the texture, lighting, and configuration of surfaces will all have an influence. ACI Committee 347R notes, however, that concrete construction tolerances of 1/2 those called for in ACI 117 are considered the achievable limit.

5.2.4 *Camber*—The contractor should camber formwork to compensate for deflection of the formwork during concrete placement. The architect should, however, specify any additional camber required to compensate for structural deflection or optical sag (the illusion that a perfectly horizontal long-span member is sagging). The architect should be aware that horizontal members are checked for compliance with tolerances and camber before the removal of the forms and shores.

5.2.5 *Joints and details*—Location, number, and details of items such as openings, contraction joints, construction joints, and expansion joints should be shown on the design plans or the architect should specify a review of the proposed location of all of these details as shown on the formwork drawings. (Some guidance on joint locations can be found in ACI 224R, 303R, and 332R.) Because it is impossible to disguise the presence of joints in the form face, it is important for their positions to be predetermined and, if possible, planned as part of the architectural effect.

The architect can plan joint locations between surface areas on a scale and module suitable to the size of available materials and prevailing construction practices. If this is not aesthetically satisfactory, dummy joints can be introduced to give a smaller pattern. Actual joints between sheathing materials can be masked by means of rustication strips (splayed fillets) attached to the form face. Rustication strips at horizontal and vertical construction joints can also create crisp edges accented by shadow lines instead of the potential ragged edge of a construction joint left exposed to full view. Special care should be taken during placement and vibration to minimize bugholes and honeycombing that form when air is trapped beneath horizontal rustications.

Sometimes construction joints in beams can be concealed above the support columns and joints in floors above their supporting beams instead of in the more customary regions of low shear.

5.2.6 *Ties and inserts*—Form ties and accompanying tie holes are an almost inescapable part of wall surfaces. Architects frequently integrate tie holes into the visual design quality of the surface. If this is planned and any effects or materials other than those provided in Section 5.3.4 are desired, they should be clearly specified as to both location and type.

Where tie holes are to be patched or filled, the architect should specify the treatment desired, unless it has been shown on the preconstruction mockup.

5.2.7 *Cover over reinforcing steel*—Adequate cover over reinforcement, as required by codes, is needed for protection of steel and long-term durability of the concrete. Reinforcement that is properly located is important in the control of surface cracking. For positive assurance of maintaining required cover, the architect can specify appropriate side form spacers as defined in Section 4.3.4.

There is no advantage in specifying more cover than required by code because excessive cover can contribute to increased cracking. The architect should specify sufficient cover to allow for any reduction that will result from the incorporation of grooves or indented details and from surface treatments, such as aggregate exposure and tooling. The maximum thickness of any material to be removed should be added to basic required cover.

5.3—Materials and accessories

5.3.1 *Sheathing or form facing*—Architectural concrete form sheathing should be of appropriate quality to maintain the uniformity of concrete surfaces through multiple uses and to control deflection within appropriate limits. Plywood, steel, glass fiber-reinforced plastic, and aluminum can all be suitable as sheathing or facing materials. Select the grade or class of material needed for pressure, framing, and deflection requirements. Be sure that the chosen material meets the specification requirements for the concrete surface texture. Procedures for controlling the rusting of steel should be carefully followed.

5.3.2 *Structural framing*—Form facing can be supported with lumber, steel, or aluminum members straight and rigid enough to meet the architectural specifications.

5.3.3 *Form liners*—A form liner is a material attached to the inside face of the form to alter or improve surface texture or quality of the concrete. It is not required structurally. Wood, rigid plastic, elastomeric materials, and glass fiber-reinforced plastics are all suitable liner materials when carefully detailed and fabricated. Plastics should be handled and assembled with care to avoid distortion caused by daily temperature cycles at the job site.

5.3.4 *Form ties*—Form-tie assemblies for architectural concrete should permit tightening of forms and leave no metal closer to the surface than 1-1/2 in. (38 mm) for steel ties and 1 in. (25 mm) for stainless steel ties. The ties should not be fitted with lugs, cones, washers, or other devices that will leave depressions in the concrete less than the diameter of the device, unless specified. Ties should be tight fitting or tie holes in the form should be sealed to prevent leakage at the holes in the form. If textured surfaces are to be formed, ties should be carefully evaluated as to fit, pattern, grout leakage, and aesthetics.

5.3.5 *Side form spacers*—Side form spacers, as defined in Section 4.3.4, are particularly important in architectural concrete to maintain adequate cover over reinforcing steel and to prevent development of rust streaking on concrete surfaces. Plastic, plastic-protected, rubber-tipped, or other noncorroding spacers should be attached to the reinforcing bar so that they do not become dislodged during concrete placement and vibration. The number and location of the side form spacers should be adequate for job conditions.

5.4—Design

5.4.1 *Special considerations*—The general procedure will follow the principles outlined in Chapter 2. The formwork engineer/contractor, however, will frequently have limitations imposed by the architectural design. Some of these considerations are: tie spacing and size, form facing preferences, location and special treatment of form joints, special tolerances, and use of admixtures. Because these factors can influence form design, they should be fully reviewed at the beginning of the form design process.

5.4.2 *Lateral pressure of concrete*—Architectural concrete can be subjected to external vibration, revibration, set retardants, high-range water-reducing admixtures, and slumps greater than those assumed for determining the lateral pressure as noted in Section 2.2.2. Particular care should be exercised in these cases to design the forms for the increased lateral pressures resulting from sources noted in Section 2.2.2.

5.4.3 *Structural considerations*—Because deflections in the contact surface of the formwork reflect directly in finished surfaces under varying light conditions, forms for architectural concrete should be designed carefully to minimize deflections. In most cases, deflections govern design rather than bending (flexural stress) or horizontal shear. Deflections of sheathing, studs, and wales should be designed so that the finished surface meets the architectural specifications. Limiting these deflections to $l/400$, where l is the clear span between supports, is satisfactory for most architectural formwork. Forms bow with reuse; therefore, more bulging will be reflected in the surface formed after several uses. This effect should be considered when designing forms.

When tie size and spacing are limited by the architect, the formwork engineer/contractor may have to reverse the usual procedure to arrive at a balanced form design. Given the capacity of the available tie and the area it supports, the formwork engineer/contractor can find the allowable pressure, design supporting members, and establish a rate of concrete placing.

Where wood forms are used, stress-graded lumber (or equivalent) free of twists and warps should be used for structural members. Form material should be sized and positioned to prevent deflections detrimental to the surfaces formed. Joints of sheathing materials should be backed with structural members to prevent offsets.

5.4.4 *Tie and reanchor design*—Tie layout should be planned. If the holes are to be exposed as part of the architectural concrete, tie placement should be symmetrical with the member formed. If tie holes are not to be exposed, ties should be located at rustication marks, control joints, or other points where the visual effect will be minimized.

Externally braced forms can be used instead of any of the aforementioned methods to avoid objectionable blemishes in the finished surface. Externally braced forms, however, can be more difficult and more costly to build.

Consideration should be given to reanchoring forms in preceding or adjacent placements to achieve a tight fit and prevent grout leakage at these points. Ties should be located as close as possible to the construction joint to facilitate reanchoring the form to adjacent placements.

5.4.5 *Joints and details*—In architectural concrete, joints should, where feasible, be located at the junction of the formwork panels. At contraction or construction joints, rustication strips should be provided and fastened to the face of forms.

Corners should be carefully detailed to prevent grout leakage. Sharp corners should, wherever possible, be eliminated by the use of chamfer strips except when prohibited by project specifications.

5.4.6 *Tolerances*—The formwork engineer/contractor should check for dimensional tolerances specified by the architect that can have a bearing on the design of the forms. If no special tolerances are given, the formwork engineer/ contractor can use ACI 117 tolerances for structural concrete.

5.5—Construction

5.5.1 *General*—Forms should be carefully built to resist the pressures to which they will be subjected and to limit deflections to a practicable minimum within the tolerances specified. Joints in structural members should be kept to a minimum and, where necessary, should be suitably spliced or otherwise constructed to maintain continuity.

Pour pockets for vibrating or placing concrete should be planned to facilitate careful placement and consolidation of the concrete to prevent segregation, honeycomb, sanding, or cold joints in the concrete. The location of pour pockets should be coordinated with the architect.

Attachment of inserts, rustication strips, and ornamental reliefs should be planned so that forms can be removed without exerting pressure on these attachments.

Where special forming systems are specified by the engineer of the project for structural purposes (such as one- and two-way joist systems) in areas that are considered architectural, the architect and engineer should coordinate their requirements to be sure the architectural effect is consistent with the forming method and material specified.

Forms that will be reused should be carefully inspected after each use to ensure that they have not become damaged, distorted, disassembled, or otherwise unable to perform as designed.

5.5.2 *Sheathing and jointing*—Contact surfaces of the formwork should be carefully installed to produce neat and symmetrical joint patterns, unless otherwise specified. Joints should be either vertical or horizontal and, where possible, should be staggered to maintain structural continuity.

Nailing should be done with care using hammers with smooth and well-dressed heads to prevent marring of the form surfaces. When required, box nails should be used on the contact surface and should be placed in a neat pattern.

Wherever possible, sheathing or panel joints should be positioned at rustication strips or other embedded features that can conceal or minimize the joint.

Construction joints should be formed with a grade strip attached to the form to define a clean straight line on the joint of the formed surface. Formwork should be tightened at a construction joint before the next placement to prevent seepage of water between the form and previously placed concrete surfaces.

Architectural concrete forms should be designed to resist water leakage and avoid discoloration. One method to prevent water loss from the concrete at the joints between sections of the formwork and at construction joints is to attach a gasket of flexible material to the edge of each panel. The gasket is compressed when the formwork is assembled or placed against the existing concrete. Caulk, tape, joint compound, or combinations of these can be used to seal joints. In all cases, unsupported joints between sheathing sheets should be backed by framing. Water-tight forms require more care during vibration to remove entrapped air that can cause bug holes.

Textured surfaces on multilift construction should be separated with rustication strips or broad reveals because accumulation of construction tolerances, random textures, or both, prevent texture matching. Furthermore, the grout seal between the bottom of a textured liner and the top of the previous placement is impractical without the rustication strip.

5.5.3 *Cleaning, coating, and release agents*—Form coatings or releasing agents should be applied before reinforcing steel is placed and should be applied carefully to avoid contacting adjacent construction joints or reinforcing. No form coating should be used unless it can be demonstrated not to stain the concrete or impair the adhesion of paints or other surface treatments.

Form sealers should be tested to ensure that they will not adversely affect the texture of the form lining material.

Ties that are to be pulled from the wall should be coated with nonstaining bond breaker or encased in sleeves to facilitate removal.

Forms should be carefully cleaned and repaired between uses to prevent deterioration of the quality of surface formed. Film or splatter of hardened concrete should be thoroughly removed.

5.5.4 *Ornamental liners and detail*—Ornamental concrete is usually formed by elastomeric molds or wood, plastic, or plaster waste molds. Members making up wood molds should be kerfed on the back wherever such members can become wedged between projections in the ornament. Molds should be constructed so that joints will not be opened by slight movement or swelling of the wood. Joints in the molds should be made inconspicuous by pointing.

The molds should be carefully set in the forms and securely held in position to reproduce the design shown on the plans. Where wood forms adjoin molds, the wood should be neatly fitted to the profile of the mold and all joints should be carefully pointed. The molds and the adjacent wood forms should be detailed so that the wood forms can be stripped without disturbing the molds. The edge of the mold or pattern strip should be tapered to a slight draft to permit removing the detail material without damaging the concrete. Special provisions should be made for early form removal, retardation, or both when sandblasting, wire brushing, or other treatments are required.

Form liners should be attached securely with fasteners or glue recommended by the manufacturer. The form behind the liner should hold the fasteners. The surfaces should be cleaned and dried thoroughly so that the glue will bond. Do not use glue at temperatures lower than those recommended by the manufacturer.

5.6—Form removal

5.6.1 *Avoiding damage*—When concrete surfaces are to be left as cast, it is important not to damage or scar the concrete face during stripping. Forms should be supported so that they do not fall back or against the architectural surface. The use of pry bars and other stripping tools should be strictly supervised. In no case should pry bars be placed directly against the concrete. Even the use of wood or plastic wedges does not ensure that damage will not occur. Once formwork is removed, the architectural surfaces should be protected from continuing construction operations.

5.6.2 *Concrete strength*—It is desirable for architectural concrete to have a higher compressive strength than normal for stripping. This can be accomplished by adjusting the mixture proportions or leaving forms in place longer. If concrete is not strong enough to overcome the adhesion between the form surface and the concrete, concrete can scale or spall. Therefore, a good quality surface might require the forms to stay in place longer. The longer the forms stay in place, however, the darker the concrete will become. The engineer/architect should specify what concrete strength is required before stripping can take place.

5.6.3 *Uniformity*—To ensure surface quality, uniformity in stripping time and curing practices are essential. Where the objective is to produce as consistent an appearance as possible, it is beneficial to protect the concrete by leaving the formwork in place somewhat longer than normal. Early exposure of concrete to the air affects the manner in which the surface dries. The ambient conditions can influence the eventual color of the concrete.

5.6.4 *Avoiding thermal shock*—Cold-weather concreting requires that special attention be paid to the sudden temperature change of concrete. To avoid thermal shock and consequent crazing of the concrete surface, the change in temperature of the concrete should be controlled within the limits outlined in ACI 303R. This can be accomplished by heating the work area, leaving the forms in place to contain the heat of hydration, or by insulating the concrete after the forms have been removed (refer to ACI 306R). Positive steps should be taken to inspect, record, and document the procedures used to cure the concrete.

CHAPTER 6—SPECIAL STRUCTURES

6.1—Discussion

Formwork for all structures should be designed, constructed, and maintained in accordance with recommendations in Chapters 1 to 4. This section deals with the additional requirements for formwork for several special classes of work. ACI 344R contains information on design and construction of circular prestressed-concrete structures.

6.2—Bridges and viaducts, including high piers

6.2.1 *Discussion*—The construction and removal of formwork should be planned in advance. Forms and supports should be sufficiently rigid to ensure that the finished structure will fulfill its intended structural function and that exposed concrete finishes will present a pleasing appearance to the public.

6.2.2 *Shoring and centering*—Recommended practice in Sections 3.5 and 3.7 for erection and removal should be followed. In continuous structures, support should not be released in any span until the first and second adjoining spans on each side have reached the specified strength. For post-tensioned bridges, the shore design should consider the resulting redistribution of loads on the shores similar to the effects discussed in Section 3.8.7.

6.2.3 *Forms*—Forms can be of any of a large number of materials but most commonly are wood or metal. They should be built mortar-tight of sound material strong enough to prevent distortion during placing and curing of the concrete.

6.3—Structures designed for composite action

6.3.1 *Recommendations*—Structures or members that are designed so that the concrete acts compositely with other materials or with other parts of the structure present special forming problems that should be anticipated in the design of the structure. Requirements for shoring or other deflection control of the formwork should be clearly presented by the engineer/architect in the specifications. Where successive placements are to act compositely in the completed structure, deflection control becomes extremely critical.

Shoring, with or without cambering portions of the structure during placement and curing of the concrete, should be analyzed separately for the effects of dead load of newly placed concrete and for the effect of other construction loads that can be imposed before the concrete attains its design strength.

6.3.2 *Design*—Formwork members and shores should be designed to limit deflections to a practical minimum consistent with the structural member being constructed. Where camber is specified for previously installed components of the structure, allowance should be made for the resultant preloading of the shores before application of the dead load of concrete.

In members constructed in several successive placements, such as box-girder structures, formwork components should be sized, positioned, supported, or all three to minimize progressive increases in deflection of the structure that would excessively preload the reinforcing steel or other portions of the composite member.

In multistory work where shoring of composite members is required, consideration should be given to the number of stories of shores necessary, in conjunction with the speed of construction and concrete strengths, to minimize deflections due to successive loadings. Distinction should be made in such analyses for shores posted to relatively unyielding support, such as foundations, instead of to structures or members already in elastic support (refer to Section 3.8).

Composite construction can have beams of relatively light cross sections that are fully adequate when construction is complete. During construction, these beams may not be laterally supported by the formwork, thus leaving them with a high slenderness ratio and reduced beam strength. The engineer/architect should alert the contractor to this problem in general notes on the structural plans or in notes on applicable plans when this condition exists. The formwork engineer/contractor should be alert to this possibility and provide shoring or lateral support where needed.

6.3.3 *Erection*—Construction, erection of formwork, or both for composite construction follows basic recommendations contained in Chapter 3. Shoring of members that will act compositely with the concrete to be placed should be done with great care to ensure sufficient bearing, rigidity, and tightness to prevent settlement or deflections beyond allowable limits. Wedges, shims, and jacks should be provided to permit adjustment if required before or during concreting, as well as to permit removal without jarring or impacting the completed construction. Provision should be made for readily checking the accuracy of position and grade during placement. Even though adjustment of forms can be possible during or after placing, it is not recommended. Any required adjustment should be made before the initial set of the concrete.

Where camber is required, a distinction should be made between that part which is an allowance for settlement or deflection of formwork or shoring and that which is provided for design loadings. The former should generally be the responsibility of the formwork engineer/contractor who designs the forms and supports unless such camber is stipulated by the engineer/architect. Measurement of camber provided for structural design loadings should be made after hardening of the concrete but before removal of the supports (also refer to Section 1.4.5). This is because the structural deflection occurring upon removal of the supports is a function of the structural design and cannot be controlled by the contractor.

6.3.4 *Removal*—In addition to meeting the provisions of Section 3.7, forms, supports, or both should be removed only after tests and specified curing operations indicate to the satisfaction of the engineer/architect that the most recently placed concrete has attained the strength required to develop composite action, and then only after approval of the engineer/architect. The sequence of such removal should be approved by the engineer/architect.

6.4—Folded plates, thin shells, and long-span roof structures

6.4.1 *Discussion*—For long-span and space structures requiring a complex, three-dimensional design analysis and presenting three-dimensional problems in formwork design, erection, and removal, formwork planning should be done by formwork engineers having the necessary special qualifications and experience. These formwork engineers should consult and cooperate with the engineer/architect to make sure that the resulting surfaces will conform to his or her design.

6.4.2—*Design*

- The engineer/architect should specify limiting values and directions of the reactive forces when the falsework is supported by the permanent structure.
- When applicable, the engineer/architect should include a decentering sequence plan with the bidding documents as a basis for the design of the forming and support system to be used by the contractor.
- *Lateral loads*—In determining the lateral forces acting on the formwork, the wind load should be calculated on the basis of a minimum of 15 lb/ft^2 (0.72 kPa) of projected vertical area as specified for wall forms in Section 2.2.3. For structures such as domes, negative forces due to suction created by the wind on the leeward side of the structure should be considered.
- *Analysis*—The provisions of Sections 2.1.1 and 2.3 should be adhered to in formwork planning.

Assumed design loads should be shown on the formwork drawings. Complete stress analyses should be prepared by competent structural engineers, and the maximum and minimum values of stress, including reversal of stress, should be shown for each member for the most severe loading conditions. Consideration should be given to unsymmetrical or eccentric loadings that might occur during concrete placement and during erection, decentering, or moving of travelers. The vertical or lateral deflection of the moving forms or travelers, as well as the stability under various loads, should be investigated to confirm that the formwork will function satisfactorily and that the concrete tolerances will be met.

Particular care should be taken in the design and detailing of individual members and connections. Where truss systems are used, connections should be designed to keep eccentricities as small as possible to minimize deflections or distortions.

Because the weight of the formwork can be equal to or greater than the design live load of the structure, form details should be designed to avoid the formwork hanging up and overloading the structure during decentering.

Due to the special shapes involved, tolerances based on functions of these shapes should be specified by the engineer/architect in the bidding documents.

6.4.3 *Drawings*—When required, the formwork engineer/contractor should submit detailed drawings of the formwork for approval of the engineer/architect.

These drawings should show the proposed concrete placing sequence and the resulting loads. To ensure that the structure can assume its deflected shape without damage, the decentering or handling sequence of the formwork should be shown on the drawings. The formwork design, drawings, and procedures should comply with federal and local safety laws, as well as the contract documents.

Deflection of these structures can cause binding between the form and the concrete during decentering. Formwork drawings and form details should be planned to prevent binding and facilitate stripping of forms. Drawings should show such details as type of inserts and joints in sheathing where spreading of the form can result in the form becoming keyed into the concrete.

6.4.4 *Approval*—The engineer/architect should review the design and drawings for the formwork and the procedures for construction to ensure the structural integrity of the permanent structure. The engineer/architect should approve in writing the loads imposed by the formwork, the sequence of the concrete placing operations, and the timing and procedures of decentering and stripping.

6.4.5 *Construction*—In planning and erecting formwork, provisions should be made for adequate means of adjustment during placing where necessary. Telltales should be installed to check alignment and grade during placement. Where the forming system is based on a certain placing sequence, that sequence should be clearly defined and adhered to in the field.

6.4.6 *Removal of formwork*—Formwork should be removed and decentered in accordance with the procedure and sequence specified on the form drawings or on the contract documents. Decentering methods used should be planned to prevent any concentrated reaction on any part of the permanent structure. Due to the large deflections and the high dead load-to-live load ratio common to this type of structure, decentering and form removal should not be permitted until specified tests demonstrate that the concrete strength and the modulus of elasticity specified in contract documents have been reached. Moduli of elasticity can determine time of decentering, although required compressive strengths may already have been attained. Decentering should begin at points of maximum deflection and progress toward points of minimum deflection, with the decentering of edge members proceeding simultaneously with the adjoining shell.

6.5—Mass concrete structures

6.5.1 *Discussion*—ACI 116R defines mass concrete as "any volume of concrete with dimensions large enough to require that measures be taken to cope with generation of heat from hydration of the cement and attendant volume change to minimize cracking." Mass concrete occurs in heavy civil engineering construction, such as in gravity dams, arch dams, gravity-retaining walls, lock walls, power-plant structures, and large building foundations (ACI 207.1R). Special provisions are usually made to control the temperature rise in the mass by the use of cement or cementitious material combinations possessing low or moderate heat-generating characteristics, by postcooling (cooling the fresh concrete) or by placing sequence. Heat rise in mass concrete is most often controlled by replacement of cement with pozzolans, particularly fly ash.

Formwork for mass concrete falls into two distinct categories, namely, low and high lift. Low-lift formwork, for heights of 5 to 10 ft (1.5 to 3 m), usually consists of multiuse steel cantilever form units that incorporate their own work platforms and, on occasion, lifting devices. High-lift formwork is comparable with the single-use wood forms used extensively for structural concrete.

6.5.2 *Lateral pressure of concrete*—The lateral pressure formulas for concrete placed in walls can be used for mass concrete (refer to Section 2.2.2). The formwork engineer needs to carefully review the concrete mixture proportion to determine the appropriate formula from Section 2.2.2. Concrete additives or cement substitutes can improve heat generation characteristics, but the same materials can increase concrete set time and increase lateral pressures.

Consideration should be given to placing sequence in the determination of pressure. Frequently, concrete is layered in such a way that the fresh concrete rate of placement locally is substantially greater than the average rate of placement. Local lateral pressures can be greater than would be estimated on the basis of the average rate of placement. In addition, the use of large concrete buckets with rapid discharge of concrete can cause high impact loads near the forms.

6.5.3 *Design consideration*—Mass concrete forming can require special form tie and anchor design.

6.5.3.1—Forming sloping surfaces requires ties or anchors to resist pressure forces that are perpendicular to the face of the form. Using horizontal ties will leave the vertical component of pressure untied. Vertical (hold down) anchors are required.

6.5.3.2—Forms tied or anchored to a rock face require particular care. Often, rock anchors are placed before the forms are erected. This requires the form designer to accommodate tie and anchor misalignment. Rock anchors should be checked to ensure that the anchor can resist the tie forces.

6.5.3.3—Bending and welding of high tensile steel tie rods should not be permitted without the approval of the tie manufacturer. Any approved welding should be by a certified welder using approved written welding procedures.

6.5.3.4—The capacity of anchors and form ties embedded in previously placed concrete is dependent on the strength of the concrete, which is very low at early ages. The embedded strength should be sufficient to sustain design loadings from the new placement and initial bolting stresses.

6.5.4 *Tolerances*—Refer to Section 3.3 and ACI 117.

6.6—Underground structures

6.6.1 *Discussion*—Underground structures differ from corresponding surface installations in that the construction takes place inside an excavation instead of in the open, providing unique problems in handling and supporting formwork and in the associated concrete placing. As a result, four factors usually make the design of formwork for underground structures entirely different than for their above-ground counterparts. First, concrete to fill otherwise inaccessible areas can be placed pneumatically or by positive displacement pump and pipeline. Second, rock is sometimes used as a form backing, permitting the use of rock anchors and tie rods instead of external bracing and shores. Third, the limits of the excavation demand special handling equipment that adds particular emphasis to the removal and reuse of forms. Fourth, rock surfaces can sometimes be used for attaching hoisting devices.

When placement is done by pneumatic or positive displacement pump and pipeline methods, the plastic concrete is forced under pressure into a void, such as the crown of a tunnel lining. For more information on the pumping process, refer to ACI 304.2R.

6.6.2—*Design loads*

6.6.2.1 *Vertical loads*—Vertical and construction loads assumed in the design of formwork for underground structures are similar to those for surface structures, with the exception of unusual vertical loads occurring near the crown of arch or tunnel forms and flotation or buoyancy effect beneath tunnel forms.

In placing concrete in the crowns of tunnel forms, pressures up to 3000 lb/ft^2 (144 kPa) have been induced in areas of overbreak and near vertical bulkheads from concrete placed pneumatically or by positive displacement pump. Overbreak is the excess removal of rock or other escavated material above the forms beyond the required tunnel lining thickness. Until more definite recommendations can be made, the magnitude and distribution of pressure should be determined by the formwork engineer. The assumed pressure should not be less than 1500 lb/ft^2 (72 kPa) acting normally to the form plus the dead weight of the concrete placed pneumatically or by pump.

6.6.2.2 *Lateral loads*—For shafts and exterior walls against rock, the values listed in Section 2.2.2 should apply.

When the shaft form relies on the single shear value of embedded anchors in the previous placement as a means of support, the minimum time lapse between successive placements (or minimum concrete strength) and maximum allowable loading additional to the dead weight of the form should be specified.

For arch forms and portions of tunnel forms above the maximum horizontal dimension or spring line of the form, the pressure should be compatible with the pressures discussed under vertical loads in Section 6.6.2.1.

6.6.3 *Drawings*—In addition to the provisions of Chapters 1, 2, and 3, the following data should be included on the drawings for specialized formwork and formwork for tunnels:

- All pressure diagrams used in the design of the form, including diagrams for uplift, for unbalanced lateral or vertical loads, for pressurized concrete, or for any other load applicable to the particular installation;
- Recommended method of supplemental strutting or bracing to be employed in areas where form pressures can exceed those listed due to abnormal conditions;
- Handling diagrams and procedures showing the proposed method of handling the form during erection or installation for concrete placement plus the method of bracing and anchorage during normal operation;
- Concrete placement method and, for tunnel arch forms, whether the design is based on the unit or bulkhead system of concrete placement or the continuously advancing slope method; and
- The capacity and working pressure of the pump and the size, length, and maximum embedment of the discharge line when placement by pumping is anticipated.

6.6.4 *Construction*—The two basic methods of placing a tunnel arch entail problems in the construction of the formwork that require special provisions to permit proper reuse. These two basic methods are commonly known as the bulkhead method and the continuously advancing slope method.

The former is used exclusively where poor ground conditions exist, requiring the lining to be placed concurrently with tunnel driving operations. It is also used when some factor, such as the size of the tunnel, the introduction of reinforcing steel, or the location of construction joints, precludes the advancing slope method. The advancing slope method, a continuous method of placement, is usually preferred for tunnels driven through competent rock, ranging between 10 and 25 ft (3 and 8 m) in diameter and at least 1 mi (1.6 km) in length.

The arch form for the bulkhead method is usually fabricated into a single unit between 50 and 150 ft (15 and 45 m) long, which is stripped, moved ahead, and re-erected using screw jacks or hydraulic rams. These are permanently attached to the form and supporting traveling gantry. The arch form for the continuously advancing slope method usually consists of eight or more sections that range between 15 and 30 ft (5 and 9 m) in length. These are successively stripped or collapsed, telescoped through the other sections, and re-erected using a form traveler.

Although the minimum stripping time for tunnel arch forms is usually established on the basis of experience, it can be safely predetermined by tests. At the start of a tunnel arch concreting operation, the recommended minimum stripping time is 12 h for exposed surfaces and 8 h for construction joints. If the specifications provide for a reduced minimum stripping time based on site experience, such reductions should be in time increments of 30 min or less and should be established by laboratory tests and visual inspection and surface scratching of sample areas exposed by opening the form access covers. Arch forms should not be stripped prematurely when unvented groundwater seepage could become trapped between the rock surface and the concrete lining.

6.6.5 *Materials*—The choice of materials for underground formwork is typically predicated on the shape, degree of reuse and mobility of the form, and the magnitude of pump or pneumatic pressures to which it is subjected. Usually, tunnel and shaft forms are made of steel or a composite of wood and steel. Experience is important in the design and fabrication of a satisfactory tunnel form due to the nature of the pressures developed by the concrete, placing techniques, and the high degree of mobility required.

When reuse is not a factor, plywood and tongue-and-groove lumber are sometimes used for exposed surface finishes. High humidity in underground construction alleviates normal shrinkage and warping.

CHAPTER 7—SPECIAL METHODS OF CONSTRUCTION

7.1—Recommendations

The applicable provisions of Chapters 2, 3, and 4 also apply to the work covered in this chapter.

7.2—Preplaced-aggregate concrete

7.2.1 *Discussion*—Preplaced-aggregate concrete is made by injecting (intruding) mortar into the voids of a preplaced mass of clean, graded aggregate. For normal construction, the preplaced aggregates are vibrated thoroughly into forms and around reinforcing and then wetted and kept wet until the injection of mortar into the voids is completed. In underwater construction, the mortar displaces the water and fills the voids. In both types of construction, this process can create concrete with a high content of coarse aggregate.

The injected mortar contains water, fine sand, portland cement, pozzolan, and a chemical admixture designed to increase the penetration and pumpability of the mortar. The structural coarse aggregate is similar to coarse aggregate for conventional concrete. It is well washed and graded from 1/2 in. (13 mm) to the largest size practicable. After compaction in the forms, it usually has a void content ranging from 35 to 45%. Refer to ACI 304.1R.

7.2.2 *Design considerations*—Due to the method of placement, the lateral pressures on formwork are considerably different from those developed for conventional concrete as given in Section 2.2.2. The formwork engineer/contractor should be alerted to the unique problems created by preplaced-aggregate, by mass placings where heat of hydration and drying shrinkage are critical, and by differential pressures in the form structure when mortar injection varies greatly from one form face to another. For additional information, refer to ACI 359, ACI 207.1R, and ACI SP-34. Because of the pressure created during aggregate packing and mortar pumping, forms that mortar is injected through should be anchored and braced far more securely than for ordinary concrete. Particular attention should be paid to uplift pressures created in battered forms. Provision should be made to prohibit even the slightest uplift of the form. Injection pipes spaced 5 to 6 ft (1.5 to 1.8 m) apart, penetrating the face of the form, require that the form be checked for structural integrity as well as a means of plugging or shutting off the openings when the injection pipes are removed. Some of these problems are reduced where mortar can be injected vertically in open top forms.

Forms, ties, and bracing should be designed for the sum of:

a) The lateral pressure of the coarse aggregate as determined from the equivalent fluid lateral pressure of the dry aggregate using the Rankine or Coulomb theories for granular materials; or a reliable bin action theory (refer to theories and references presented in ACI 313 and ACI 313R); and

b) The lateral pressure of the injected mortar; as an equivalent fluid the mortar normally weighs 130 lb/ft^3 (21 kN/m^3), but can weigh as much as 200 lb/ft^3 (32 kN/m^3) for high-density mortars.

The time required for the initial set of the fluidized mortar (from 1 to 2 h) and the rate of rise should be ascertained. The maximum height of fluid to be assumed in determining the lateral pressure of the mortar is the product of the rate of rise (ft/h) and the time of initial set in hours. The lateral pressure for the design of formwork at any point is the sum of the pressures determined from Steps (a) and (b) for the given height.

7.2.3 *Construction*—In addition to the provisions of Chapter 3, the forms should be mortar-tight and effectively vented because preplaced-aggregate concrete entails forcing mortar into the voids around the coarse aggregate.

Where increased lateral pressures are expected, the workmanship and details of formwork should be of better quality than formwork for conventional concrete.

7.2.4 *Materials for formwork*—For unexposed surfaces, mortar-tight forms of steel or plywood are acceptable. Absorptive form linings are not recommended because they permit the coarse aggregate to indent the lining and form an irregular surface. Form linings, such as hardboard on common sheathing, are not successful because they do not transmit the external form vibration normally used for ensuring a void-free finished surface. Where external vibration is used, added strength is needed in the form.

7.3—Slipforms

7.3.1 *Discussion*—Refer to ACI 313 for silo construction. Slipforming is a quasicontinuous forming process in which a special form assembly slips or moves in the appropriate direction leaving the formed concrete in place. The process is, in some ways, similar to an extrusion process. Plastic concrete is placed in the forms, and the forms can be thought of as moving dies to shape the concrete. The rate of movement of the forms is regulated so the forms leave the concrete only after it is stiff enough to retain its shape while supporting its own weight and the lateral forces caused by wind and equipment. Formwork of this type can be used for vertical structures, such as silos, storage bins, building cores, bearing wall buildings, piers, chimneys, shaft linings, communication and observation towers, nuclear shield walls, and similar structures.

Horizontal slipforming lends itself to concrete structures, such as tunnel linings, water conduits, drainage channels, precast elements, canal linings, highway median barriers, pavements, curbs, shoulder barriers, and retaining walls.

Vertical slipforms, concreted while rising, are usually moved in small increments by jacks that propel themselves on smooth steel rods or tubing embedded in or attached to the hardened concrete. Horizontal slipforms generally move on a rail system, tractor treads, wheels, and other similar means resting on a shaped berm. Working and storage decks and finisher's scaffolding are attached to and carried by the moving formwork.

The vertical or horizontal movement of forms can be a continuous process or a planned sequence of finite placements.

Slipforms used on structures such as tunnels and shafts should comply with the applicable provisions of Section 6.6. Slipforms used on mass concrete structures, such as dams, should comply with the applicable provisions of Section 6.5.

7.3.2—*Vertical slipforms*

7.3.2.1—A vertical slipform system has five main components: sheathing, wales, yokes, jacks and jackrods, and working or storage decks and scaffolding.

The sheathing or vertical forms can be wood staves, plywood, metal, glass fiber-reinforced plastic, wood, or a combination of these materials. The function of the sheathing is to contain and shape the concrete.

Wales have three main functions:

- Support and hold the sheathing in place;
- Transmit the lifting force from the yokes to the sheathing and to the other elements of the form; and
- Provide support for various platforms and scaffolding.

Yokes support the wales at regular intervals with their legs, transmit the lifting forces from the jacks to the wales, and resist the lateral force of plastic concrete within the form.

The jacks, installed on the yoke's beams, climb up the jackrods and provide the force needed to raise the entire slipform system.

Various platforms, decks, and scaffolding complete the slipform system. They provide space for storing concrete, reinforcing steel, and embedments, and serve as a working area for placing and finishing.

7.3.2.2 *Design and construction considerations*—Slipforms should be designed by engineers familiar with slipform construction. Construction of the slipform and slipping should be carried out under the immediate supervision of a person experienced in slipform work. Drawings should be prepared by a slipform engineer employed by the contractor. The drawings must show the jack layout, formwork, working decks, and scaffolds. A developed elevation of the structure should be prepared, showing the location of all openings and embedments. The slipform engineer should be experienced in the use of the exact brand of equipment to be used by the contractor because there is significant variation in equipment between manufacturers.

7.3.2.3 *Vertical loads*—In addition to dead loads, live loads assumed for the design of decks should not be less than the following:

Sheathing and joists .... 75 lb/ft^2 (3.6 kPa)
or concentrated buggy wheel loads, whichever is greater

Beams, trusses, and wales .... 50 lb/ft^2 (2.4 kPa)
Light-duty finishers' scaffolding .... 25 lb/ft^2 (1.2 kPa)

7.3.2.4 *Lateral pressure of concrete*—The lateral pressure of fresh concrete to be used in designing forms, bracing, and wales can be calculated as follows.

Inch-pound version:

$$p = c_1 + \frac{6000R}{T}$$

where

c_1 = 100;
p = lateral pressure, lb/ft^2;
R = rate of concrete placement, ft/h; and
T = temperature of concrete in the forms, °F.

SI version:

$$p = c_1 + \frac{524R}{T + 17.8}$$

where

c_1 = 4.8;
p = lateral pressure, kPa;
R = rate of concrete placement, m/h; and
T = temperature of concrete in the forms, °C.

c_1 = 100 lb/ft^2 (4.8 kPa) is justified because vibration is slight in slipform work because the concrete is placed in shallow layers of 6 to 10 in. (150 to 250 mm) with no revibration. For some applications, such as gas-tight or containment structures, additional vibration can be required to achieve maximum density of the concrete. In such cases, the value of c_1 should be increased to 150 lb/ft^2 (7.2 kPa).

7.3.2.5 *Tolerances*—Prescribed tolerances for slipform construction of building elements are listed in ACI 117.

7.3.2.6 *Sliding operation*—The maximum rate of slide should be limited by the rate for which the forms are designed. In addition, both maximum and minimum rates of slide should be determined by an experienced slipform supervisor to accommodate changes in weather, concrete slump, initial set of concrete, workability, and the many exigencies that arise during a slide and cannot be accurately predicted beforehand. A person experienced in slipform construction should be present on the deck at all times during the slide operation.

During the initial placing of the concrete in the slipform, the placing rate should not exceed that for which the form was designed. Ideally, concrete should be placed in approximately 6 to 8 in. (150 to 200 mm) lifts throughout the slipform operation.

The level of hardened concrete in the form should be checked frequently by the use of a probing rod to establish safe lifting rates. Forms should be leveled before they are filled and should be maintained level unless otherwise required for out-of-tolerance corrections. Care should be taken to prevent drifting of the forms from alignment or designed dimensions and to prevent torsional movement.

Experience has shown that a plumb line, optical plummet, laser, or combination of these used in conjunction with a water level system is effective in maintaining the form on line and grade and for positioning openings and embedded items.

The alignment and plumbness of a structure should be checked at least once during every 4 h that the slide is in operation and preferably every 2 h. In work that is done in separate intermittent slipping operations, a check of alignment and plumbness should be made at the beginning of each slipping operation.

More frequent readings should be taken on single tall structures with relatively small plan sections, as the form system in these structures tends to twist and go out of plumb more readily.

Sufficient checks of plumbness should be provided to readily detect and evaluate movements of the form for all slipformed structures so that appropriate adjustment can be made in sufficient time by experienced personnel.

Detailed records of both vertical and lateral form movements should be maintained throughout the slipform operation.

7.3.3 *Horizontal slipforms*—The general provisions of Section 2.1.4 should be met and the formwork engineer/contractor should submit drawings of the slipform for review and approval by the engineer/architect. These drawings should show the handling diagrams, the placing procedure, and the provisions for ensuring attainment of the required concrete surfaces.

7.4—Permanent forms

7.4.1 *Discussion*—Permanent forms, or stay-in-place forms, are forms left in place that may or may not become an integral part of the structural frame. These forms can be rigid —such as metal deck, precast concrete, wood, plastics, and various types of fiberboard—or the flexible type—such as reinforced, water-repellent, corrugated paper, or wire mesh with waterproof paper backing.

When the permanent form is used as a deck form, it is supported from the main structural frame with or without an intermediate system of temporary supports. If temporary supports are required under, or to provide structural stability for, the structural frame members to support the weight of the fresh concrete without causing excessive deflection or member instability, such information should be specified by the engineer/architect.

7.4.2 *Design considerations*—If the stay-in-place form is not covered in the contract specifications because it has no function in the finished structure, the form manufacturer's specifications should be used; the manufacturer's recommended practice should be followed for size, span, fastenings, and other special features pertinent to this type of form, such as being water repellent and protected against chemical attack from wet concrete; and the minimum requirements of Chapters 2 and 3 should be followed. Particular care should be taken in the design of such forms by the formwork engineer/contractor to minimize distortion or deformation of the form or supporting members under the construction loads.

The engineer/architect who specifies the use of permanent rigid forms should consider in the structural analysis both the construction dead and live loads on the form as well as the structure's stability during construction, in addition to consideration of the form's performance in the finished structure.

When metal deck to become an integral part of the structure is used as a permanent form, its shape, depth, gage, coating, physical dimensions, properties, and intermediate temporary support should be as called for in contract documents. If structural continuity is assumed in the design of the form, the engineer of the permanent structure should specify the required number of permanent supports over which the form material should be continuous.

7.4.3—*Installation*

7.4.3.1 *Shop drawings*—The formwork engineer/contractor should submit fully detailed shop drawings for all permanent deck forms to the engineer/architect for review, approval, or both. Shop drawings should show all form thicknesses, metal gauges, physical dimensions and properties, accessories, finishes, methods of attachment to the various classes of the work, and temporary shoring requirements.

7.4.3.2 *Fastenings*—The permanent deck form should be properly fastened to supporting members and to adjacent sections of deck form and properly lapped, in accordance with manufacturers' recommendations, to provide a tight joint that will prevent loss of mortar during the placement of concrete. Where required, end closures for corrugated or fluted forms should be provided, together with fill pieces where a tight fit is required. To prevent buckling, allow for expansion of metal deck forms after fastening and before concrete placement.

Flexible types of forms (those that depend for lateral stiffness on supporting members) should be drawn tight for proper installation. Adequate temporary bracing or anchors should be provided in the plane of the top chord of the supporting members to prevent lateral buckling and rotation of these supports and to maintain the required tension in the flexible form.

Paper or metal forms used to form voids in concrete construction should be properly placed and anchored to the reinforcement and to side or deck forms with wire ties or other approved methods to prevent displacement or flotation during placing of concrete. Water should be prevented from entering voids. Where water intrusion is possible, weep holes should be provided to reduce its entrapment.

7.4.4 *Deflections*—The vertical and lateral deflections of the permanent form between supports under the load of fresh concrete should be investigated by the engineer/architect. Temporary supports, such as shoring and stringers, should be specified, if necessary, to keep deflection within desired tolerances.

7.5—Forms for prestressed concrete construction

7.5.1 *Discussion*—The engineer/architect should indicate in the contract documents any special requirements for prestressed concrete construction.

It may be necessary to provide appropriate means of lowering or removing the formwork before full prestress is applied to prevent damage due to upward deflection of resilient formwork.

Pretensioning or post-tensioning of strands, cables, or rods can be done with or without side forms of the member in place, in accordance with Section 7.5.2. Bottom forms and supporting shores or falsework should remain in place until the member is capable of supporting its dead load and anticipated construction loads, as well as any formwork carried by the member.

The concreting sequence for certain structures should also be planned so that concrete is not subjected to bending stress caused by deflection of the formwork.

7.5.2—*Design*

7.5.2.1—Where the side forms cannot be conveniently removed from the bottom or soffit form after concrete has set, such forms should be designed with slip joints or with added panel and connection strength for additional axial or bending loads that can be superimposed on them during the prestressing operation.

7.5.2.2—Side forms that remain in place during the transfer of prestressing force should be designed to allow for vertical and horizontal movements of the cast member during the prestressing operation. The form should be designed to minimize the restraint to elastic shortening in the prestressing operation. For example, small components or wrecking strips should be planned that can be removed or destroyed to relieve load on side forms as well as to eliminate their restraint during prestressing. In all cases, the restraint to shrinkage of concrete should be kept to a minimum, and the deflections of members due to prestressing force and the elastic deformation of forms or falsework should be considered in the design and removal of the forms.

7.5.2.3—For reasons of safety, when using post-tensioned, cast-in-place elevated slabs, the contractor should be careful to ensure that supporting shores do not fall out due to lifting of the slab during tensioning. For large structures where the dead load of the member remains on the formwork during prestressing, displacement of the dead load toward end supports should be considered in design of the forms and shoring, including sills or other foundation support.

7.5.3 *Construction accessories*—Hold-down or push-down devices for deflected cables or strands should be provided in the casting bed or forms. All openings, offsets, brackets, and all other items required in the concrete work should be provided for in the formwork. Bearing plates, anchorage assemblies, prestressing steel, conduits, tube enclosures, and lifting devices shown or specified to be set in concrete should be accurately located with formwork templates and anchored to remain within the tolerances given on contract documents. Quality and strength of these accessories should be as specified.

7.5.4 *Tolerances*—Prescribed ranges of tolerances for job site precast and plant manufactured precast-prestressed concrete members are given in ACI 117 and the PCI report[7.1] on tolerances.

7.5.5 *Special provisions for curing and for safety of workers*—Where necessary to allow early reuse of forms, provisions should be made to use accelerated curing processes such as steam curing, vacuum processing, or other approved methods.

Safety shields should be provided at end anchorages of prestressing beds or where necessary for the protection of workmen or equipment against possible breakage of prestressing strands, cables, or other assemblies during prestressing or casting operation.

7.6—Forms for site precasting

7.6.1 *Discussion*—Forms for site precasting are used for precast concrete items that can be either load- or nonload-bearing members for structural or architectural uses.

7.6.2 *Construction*—Exterior braces only should be used when exposed metal or filled-in pockets resulting from the use of metal ties would present an objectionable appearance.

To ensure uniformity of appearance in the cast members or units, particularly in adjacent units where differences in texture, color, or both would be visible, care should be taken that the contact surfaces of forms or form liners are of uniform quality and texture.

Form oil or retardant coatings (nonstaining, if required) should be applied uniformly and in accordance with manufacturers' recommendations for this particular class of work.

7.6.3 *Accessories*—It is particularly important in this class of work that positive and rigid devices be used to ensure proper location of reinforcement. All openings, cutouts, offsets, inserts, lift rings, and connection devices required to be set in concrete should be accurately located and securely anchored in the formwork.

The finished surfaces of members should be free of lift rings and other erection items where it will be exposed, interfere with the proper placing of precast members or other materials, or be subject to corrosion. Such items should be removed so that no remaining metal will be subject to corrosion.

The quality and strength of these accessories should be as required by the contract documents, but the lifting devices or other accessories not called for in the contract documents are the responsibility of the contractor.

7.6.4 *Tolerances*—Prescribed tolerances for precast-concrete construction are listed in ACI 117.

7.6.5 *Removal of forms*—Precast members or units should be removed from forms only after the concrete has reached a specified strength, as determined by the field-cured test cylinders or beams and job history of concrete curing.

Where required to allow early reuse of forms, provisions can be made to use accelerated curing processes, such as steam curing, or other approved methods. Methods of lifting precast units from forms should be approved by the engineer/architect.

7.7—Use of precast concrete for forms

7.7.1 *Discussion*—Precast concrete panels or molds have been used as forms for cast-in-place and precast concrete, either as permanent forms, integrated forms, or as removable, reusable forms. They have been used for both structural and architectural concrete, designed as structurally composite with the cast-in-place material or to provide a desired quality of outer surface and, in some cases, to serve both of these purposes. Concrete form units can be plain, reinforced, or prestressed, and either cast in the factory or at the job site. The most common use of precast concrete form units has been for elevated slabs acting compositely with topping concrete, as in bridge and commercial or institutional construction. Precast units are also common as ground holding systems in tunneling and as stay-in-place forms for rehabilitation of navigation lock walls.

7.7.2—*Design*

7.7.2.1 *Responsibility for design*—Where the integrated form is to act compositely with the structure concrete, the form panel should be designed by the engineer/architect who should also indicate what additional external support is required for the permanent forms. For permanent forms intended to achieve a desired architectural effect, the engineer/architect can specify surface finish and desired minimum thickness of architectural material. Design and layout of temporary forms and supporting systems should normally be the responsibility of the formwork engineer/contractor.

7.7.2.2 *Connections*—Connection details should be planned to overcome problems of mating precast members to each other and to the existing or cast-in-place structure.

7.7.2.3 *Bonding concrete form to concrete structure*—Effective bond between precast form unit and the concrete structure is essential and can be achieved by: 1) special treatment, such as grooving or roughening the form face in contact with the structure concrete; 2) use of anchoring devices extending across the interface between form panel and structure concrete; 3) a combination of 1) and 2); and 4) use of paint-on or spray-on bonding chemicals. Lifting hooks in a form unit can be designed to serve also as anchors or shear connectors.

7.7.2.4 *Code requirements*—Precast concrete forms used in composite design with cast-in-place concrete in buildings should be designed in accordance with ACI 318.

7.7.3—*During and after concreting*

7.7.3.1 *Vibration*—Thorough consolidation of site-cast concrete is required to prevent voids that would interrupt the bond of the form to structure concrete, but sufficient care should be used to prevent damage of concrete panels by contact with vibrators.

7.7.3.2 *Protection of architectural finish*—Care should be taken to avoid spilling fresh concrete on exposed surfaces, and any spilled or leaked concrete should be thoroughly removed before it has hardened. After concreting, protection of precast architectural concrete form facings may need to be considered.

7.8—Forms for concrete placed under water

7.8.1 *Discussion*—There are two basic approaches to the problem of placing concrete under water: the concrete can be mixed in the conventional manner and then placed by special methods, or the preplaced aggregate method can be used.

In the first approach, placement can be made by either pump, underwater bucket, or tremie. The tremie is a steel pipe, suspended vertically in the water, with a hopper attached to the upper end above the water surface. The lower end of the pipe, with an ejectable plug, extends to the bottom of the area to be concreted. This pipe is charged with concrete from the surface. Once the pipe is filled with concrete, it is kept full and its bottom should be kept immersed in the fresh concrete.

In the second approach, the forms are filled with coarse aggregate, which is then grouted so that the voids around the aggregate are filled as discussed in Section 7.2. The grout is introduced at the bottom and the water is displaced upward as the grout rises.

7.8.2—*Underwater bucket and tremie*

7.8.2.1 *Design*—Forms for underwater concreting are designed with the same considerations as other forms covered in Section 2.2, except that the density of the submerged concrete can be reduced by the weight of the water displaced. Because of large local pressures that can develop due to the head of concrete in the tremie, the location of the tremie and possible resulting loads on the form should be evaluated by experienced personnel. Some designers have ignored the effects of submergence because this results in a practical design that is sturdy enough to withstand the extra rigors of underwater conditions.

In tidal zones, forms should be designed for the lowest possible water level. Changes in construction schedules can transform a planned submerged placement to one made above water, thus losing the offsetting water pressure.

7.8.2.2 *Construction*—Underwater forms should be built on the surface in large units because final positioning and fitting when done under water by divers is slow and costly. For this reason, foundations should be kept simple in shape, and forms should be free of complex bracing and connection details. Through-ties, which could interfere with the concrete placing, should be avoided. Forces imposed on preassembled forms during lifting should be considered in the form design.

Forms should be carefully fitted and secured to adjacent materials or construction to avoid loss of mortar under pressure developed. If there is any water current flow past the form, small openings in the form should be avoided as they will permit washing or scouring of the fresh concrete.

When it is intended to permit concrete to overflow the form and screed it off to grade, it is essential that the form is positioned to the proper grade and is detailed so that the overflow will not interfere with the proposed method and devices for stripping.

Forms should be well detailed, and such details should be scrupulously followed so that divers employed to remove the form can visualize and plan their work before descending.

Multiuse forms can have special devices for positioning forms from above water and special stripping devices, such as hydraulic jacks, that permit releasing the form from the surface.

7.8.3—*Preplaced aggregate*

7.8.3.1 *Design*—The formwork should be designed with the same considerations as mentioned previously in Section 7.2.2.

7.8.3.2 *Construction*—It is important to ensure that silt is excluded from the forms because silt chokes the voids in the aggregate and interferes with the flow of grout. Silt, if left adhering to the aggregate, can reduce the bond between the aggregate and the grout.

The inspection of the forms before concrete placement should verify that the perimeters of the forms are effectively sealed against the leakage of grout or the intrusion of silt or other fines.

CHAPTER 8—REFERENCES

8.1—Referenced standards and reports

The standards and reports listed as follows were the latest editions at the time this document was prepared. Because these documents are revised frequently, the reader is advised to contact the proper sponsoring group if it is desired to refer to the latest version.

American Concrete Institute

116R Cement and Concrete Terminology

117 Standard Specifications for Tolerances for Concrete Construction and Materials

207.1R Mass Concrete

224R Control of Cracking in Concrete Structures

228.1R In-Place Methods to Estimate Concrete Strength
301 Specifications for Structural Concrete
303R Guide to Cast-in-Place Architectural Concrete Practice
304.1R Guide for the Use of Preplaced-Aggregate Concrete for Structural and Mass Concrete Applications
304.2R Placing Concrete by Pumping Methods
305R Hot Weather Concreting
306R Cold Weather Concreting
309.2R Identification and Control of Consolidation-Related Surface Defects in Formed Concrete
311.1R Manual of Concrete Inspection
313 Standard Practice for Design and Construction of Concrete Silos and Stacking Tubes for Storing Granular Materials
313R Commentary on Standard Practice for Design and Construction of Concrete Silos and Stacking Tubes for Storing Granular Materials
318 Building Code Requirements for Reinforced Concrete
332R Guide to Residential Cast-in-Place Concrete Construction
344R Design and Construction of Circular Prestressed Concrete Structures
347.1R Precast Concrete Units Used as Forms for Cast-in-Place Concrete
359 Code for Concrete Reactor Vessels and Containments
SP-34 Concrete for Nuclear Reactors

American Forest & Paper Association

National Design Specification for Wood Construction

Load and Resistance Factor Manual for Engineered Wood Construction

American National Standards Institute

ANSI/SEI/ASCE 7 Minimum Design Loads for Buildings and Other Structures
A48.1 Forms for One-Way Concrete Joist Construction
A48.2 Forms for Two-Way Concrete Joist Construction
A208.1 Mat-Formed Wood Particle Board

American Society of Civil Engineers

SEI/ASCE 37 Design Loads on Structures During Construction

APA—The Engineered Wood Association

Plywood Design Specification and supplements, 1997

ASTM International

A 446 Standard Specification for Steel Sheet, Zinc-Coated (Galvanized) by the Hot-Dip Process, Structural (Physical) Quality
C 532 Standard Specification for Structural Insulating Formboard (Cellulosic Fiber)
E 329 Specification for Agencies Engaged in the Testing and/or Inspection of Materials Used in Construction

Canadian Standards Association

CAN3-086-M80 Code for Engineering Design in Wood
CAN/CSA-096.1.94 Engineered Design in Wood (Limit States Design)

U.S. Department of Commerce

LLB-810a Hardboard Concrete Form Liners (Simplified Practice Recommendation)
PS 1-95 Construction and Industrial Plywood
PS20-94 American Softwood Lumber

These publications may be obtained from the following organizations:

American Concrete Institute
P.O. Box 9094
Farmington Hills, MI 48333-9094

American Forest & Paper Association
American Wood Council
1111 19th St., NW
Washington, DC 20036

American National Standards Institute
11 W. 42nd St.
New York, NY 10036

APA—The Engineered Wood Association
P.O. Box 11700
Tacoma, WA 98411

ASTM International
100 Barr Harbor Dr.
West Conshohocken, PA 19428

CSA International
178 Rexdale Blvd.
Etobicoke (Toronto) ON
M9W 1R3 Canada

U.S. Department of Commerce publications available from:

U.S. Government Printing Office
Washington, DC 20402

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CHAPTER 4 REFERENCES

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