

ACI 347R-14

Guide to Formwork for Concrete

Reported by ACI Committee 347



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Guide to Formwork for Concrete

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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 guide 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 specific 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 concrete, and prestressed concrete.

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

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Reference to this document shall not be made in contract documents. If items found in this document are desired by the Architect/Engineer to be a part of the contract documents, they shall be restated in mandatory language for incorporation by the Architect/Engineer.

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CHAPTER 1—INTRODUCTION AND SCOPE**1.1—Introduction**

Many individuals, firms, and companies are usually involved in the design of the facility to be built and in the design and construction of the formwork. The facility team typically involves structural engineers and architects who determine the requirements for the concrete structure to be built. For simplicity, the facility design team will usually be referred to as the engineer/architect, although they may be referred to separately in some situations. The formwork team may include the general contractor, formwork specialty subcontractors, formwork engineers, form manufacturers, and form suppliers. The participating companies and firms also have form designers and skilled workers executing many detailed tasks. For simplicity, the formwork team will usually be referred to as the formwork engineer/contractor, although they may be referred to separately in some situations.

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 and of the required formed surface quality of the concrete.

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.

1.2—Scope

This guide covers:

- a) A listing of information to be included in the contract documents
- b) Design criteria for horizontal and vertical loads on formwork
- c) Design considerations, including safety factors for determining the capacities of formwork accessories
- d) Preparation of formwork drawings
- e) Construction and use of formwork, including safety considerations
- f) Materials for formwork
- g) Formwork for special structures
- h) Formwork for special methods of construction

CHAPTER 2—NOTATION AND DEFINITIONS**2.1—Notation**

C_{CP}	=	concrete lateral pressure, lb/ft ² (kPa)
C_c	=	chemistry coefficient
C_w	=	unit weight coefficient
c_1	=	slipform vibration factor, lb/ft ² (kPa)
g	=	gravitational constant, 0.00981 kN/kg
h	=	depth of fluid or plastic concrete from top of placement to point of consideration in form, ft (m)
R	=	rate of placement, ft/h (m/h)
T	=	temperature of concrete at time of placement, °F (°C)
w	=	unit weight of concrete, lb/ft ³
ρ	=	density of concrete, kg/m ³

2.2—Definitions

The 2014 ACI Concrete Terminology (<http://www.concrete.org/Tools/ConcreteTerminology.aspx>) provides a comprehensive list of definitions. The definitions provided herein complement that source.

backshores—shores left in place or shores placed snugly under a concrete slab or structural member after the original formwork and shores have been removed from a small area, without allowing the entire slab or member to deflect or support its self-weight and construction loads.

brace—structural member used to provide lateral support for another member, generally for the purpose of ensuring stability or resisting lateral loads.

centering—falsework used in the construction of arches, shells, space structures, or any continuous structure where the entire falsework is lowered (struck or decentered) as a unit.

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

drop-head shore—shore with a head that can be lowered to remove forming components without removing the shore or changing its support for the floor system.

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.

falsework—temporary structure erected to support work in the process of construction; composed of shoring or vertical posting and lateral bracing for formwork for beams and slabs.

flying forms—large, prefabricated, mechanically handled sections of floor system formwork designed for multiple reuse; frequently including supporting truss, beam, or shoring assemblies completely unitized.

form—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 as well as supporting members, hardware, and necessary bracing.

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

ganged forms—large mechanically hoisted assemblies with special lifting hardware 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.

reshores—added shores placed snugly under selected panels of a deck-forming system before any primary (original) shores are removed.

reshores—shores placed snugly under a stripped concrete slab or other structural member after the original forms and shores have been removed from a full bay, 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—temporary structure with an elevated platform for supporting workers, tools, and materials.

shore—vertical or inclined support member or braced frame designed to carry the weight of the formwork, concrete, and construction loads.

slipform—a form that is pulled or raised as concrete is placed.

surface air voids—small regular or irregular cavities, usually not exceeding 0.6 in. (15 mm) in diameter, resulting from entrapment of air bubbles in the surface of formed concrete during placement and consolidation.

mized. The cost of formwork can be greater than half the total cost of the concrete structure. 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:

a) 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.

b) 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.

c) When all beams are made one depth (beams framing into girders as well as beams framing into columns), the supporting structures for the beam forms can be carried on a level platform supported on shores.

d) Considering available sizes of dressed lumber, plywood, and other ready-made formwork components and keeping beam and joist sizes constant will reduce labor cost and improve material use.

e) 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.

f) The structural design should be prepared simultaneously with the architectural design so that dimensions can be better coordinated. Minor changes in plan dimensions to better fit formwork layout can result in significant reductions in formwork costs.

g) 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.

h) Embedments for attachment to or penetration through the concrete structure should be designed to minimize random penetration of the formed surface.

i) 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.

j) Post-tensioning sequences should be carried out in stages and planned in a way that will minimize the need for additional shoring that may be required due to redistribution of post-tensioning loads.

CHAPTER 3—GENERAL CONSIDERATIONS

3.1—Achieving economy in formwork

The engineer/architect can improve the overall economy of the structure by planning so that formwork costs are mini-

3.2—Contract documents

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

The layout and design of the formwork should be a joint effort of the formwork engineer and the formwork contractor. The formwork construction in compliance with the formwork design is the responsibility of the formwork contractor. When formwork design is not by the contractor, formwork design is the responsibility of the formwork engineer. 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 jurisdictions have legal requirements defining the specific responsibilities of the engineer/architect in formwork design, review, or approval.

3.2.1 Individual specifications—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. Vague or overly restrictive requirements can make it difficult for bidders to understand exactly what is expected. Bidders can be overly cautious and overbid or misinterpret requirements and underbid. Using standard specifications such as **ACI 301** that have many input sources in development can mitigate these possible problems.

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 are not intended to represent 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. Further detailed information is given in **ACI SP-4**.

3.2.2 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 any other feature 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- or

two-way joist systems, plans should be drawn to make use of available shapes and sizes. Some variation from normal tolerances should be permitted by the specification: a) for connections of form units to other framing; and b) to reflect normal installation practices and typical used condition of the form type anticipated.

3.2.3 Finish of exposed concrete—Finish requirements for concrete surfaces should be described in measurable terms as precisely as practicable. Refer to **5.4, Chapter 7**, and **ACI 347.3R**.

3.2.4 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:

- a) Who will design the formwork
- b) Who will determine post-tensioning sequence and support needed for redistribution of loads resulting from stressing operations
- c) Who will design shoring and the reshoring system
- d) Who will inspect the specific feature of formwork and when will the inspection be performed
- e) What reviews, approvals, or both, will be required for:
 - i. Formwork drawings, calculations, or both
 - ii. Post-tensioning support
 - iii. Reshoring design
 - iv. Formwork replacement inspection
- f) Who will give such reviews, approvals, or both.

3.2.5 Contract documents—The contract documents should include all information about the structure necessary for the formwork engineer to design the formwork and prepare formwork drawings and for the formwork contractor to build the formwork such as:

- a) 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
- b) Sequence of concrete placement, if critical (examples include pour strips and hanging floors)
- c) Tolerances for concrete construction
- d) The live load and superimposed dead load for which the structure is designed and any live-load reduction used
- e) 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
- f) The location and order of erection and removal of shores for composite construction

g) Minimum concrete strength required before removal of shoring and any project specific reshoring requirements

h) 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 contractor to build the forms

i) 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

j) 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

k) Where chamfers are required or prohibited throughout the project at all element corners, such as door openings, window openings, beams, columns wall ends, and slab edges

l) Requirements for inserts, waterstops, built-in frames for openings and holes through concrete; similar requirements where the work of other trades will be attached to, supported by, or passed through formwork

m) Size and location of formed openings through a structural slab or wall should be shown on the structural drawings

n) 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

o) 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 4—DESIGN

4.1—General

4.1.1 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.

4.1.2 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 6**). For example, forms are designed by either allowable stress design (ASD) methods or load and resistance factor design (LRFD) methods. When the concrete structure becomes a part of the formwork support system, as in many multi-story buildings, it is important for the formwork engineer/contractor to recognize that the concrete structure has been designed by the strength design 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 loads (dead and live loads) on the structure. Load effects on these temporary structures and their individual components should be determined by accepted methods of structural analysis.

4.1.3 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.

4.1.4 Design deficiencies—Some design deficiencies that can lead to unacceptable performance or structural failure are:

a) Lack of allowance in design for loadings such as concrete pressures, wind, power buggies, placing equipment, and temporary material storage

b) Inadequate design of shoring, reshoring, or backshoring

c) Inadequate provisions to prevent rotation of beam forms where the slabs frame into them on only one side (Fig. 4.1.4)

d) Insufficient anchorage against uplift due to battered form faces or vertical component of bracing force on single-sided forms

e) Insufficient allowance for eccentric loading due to placement sequences

f) Failure to investigate bearing stresses between individual formwork elements and bearing capacity of supporting soils

g) Failure to design proper lateral bracing or lacing of shoring

h) Failure to investigate the slenderness ratio of compression members

i) Inadequate provisions to tie corners of intersecting cantilevered forms together

j) Failure to account for loads imposed on form hardware anchorages during closure of form panel gaps when aligning formwork

k) Failure to account for elastic shortening during post-tensioning

l) Failure to account for changing load patterns due to post-tensioning transfer

4.1.5 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

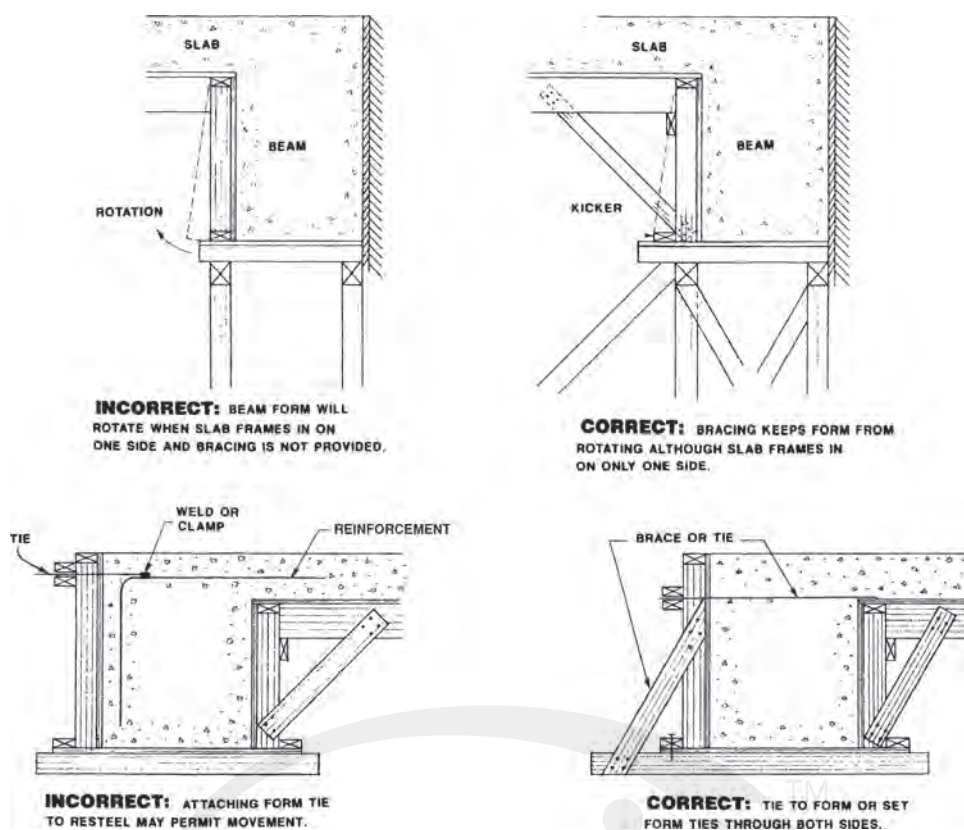


Fig. 4.1.4—Prevention of rotation is important where slab frames into beam form on only one side.

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. Design values and loading conditions should be shown on formwork drawings. As related to form use, these include formwork design values of construction live load, allowable vertical or lateral concrete pressure, maximum equipment load, required soil bearing capacity, material specification, camber required, 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:

- a) Procedures, sequence, and criteria for removal of forms, shores, reshores, and backshores and for retracting and resnugging drophead shores to allow slab to deflect and support its own weight prior to casting of next level
- b) Design allowance for construction loads on new slabs when such allowance will affect the development of shoring schemes, reshoring schemes, or both (refer to 4.5 and 5.8 for shoring and reshoring of multistory structures)
- c) Anchors, form ties, shores, lateral bracing, and horizontal lacing
- d) Means to adjust forms for alignment and grade
- e) Waterstops, keyways, and inserts
- f) Working scaffolds and runways
- g) Weepholes or vibrator holes, where required

- h) Screeds and grade strips
- i) Location of external vibrator mountings
- j) Crush plates or wrecking plates where stripping can damage concrete
- k) Removal of spreaders or temporary blocking
- l) Cleanout holes and inspection openings
- m) Construction joints, contraction joints, and expansion joints in accordance with contract documents
- n) Sequence of concrete placement and minimum elapsed time between adjacent placements
- o) Chamfer strips or grade strips for exposed corners and construction joints
- p) Reveals (rustications)
- q) Camber
- r) Mudsills or other foundation provisions for formwork
- s) Special provisions, such as safety, fire, drainage, and protection from ice and debris at water crossings
- t) Special form face requirements
- u) Notes to formwork erector showing size and location of conduits and pipes projecting through formwork
- v) Temporary openings or attachments for climbing crane or other material handling equipment.

4.2—Loads

4.2.1 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 4.5).

The formwork should be designed for a live load of not less than 50 lb/ft² (2.4 kPa) of horizontal projection, except when reductions are allowed in accordance with ASCE/SEI 37. When motorized carts are used, the live load should not be less than 75 lb/ft² (3.6 kPa).

The unfactored design load for combined dead and live loads should not be less than 100 lb/ft² (4.8 kPa), or 125 lb/ft² (6.0 kPa) if motorized carts are used.

4.2.2 Lateral pressure of concrete—The design of vertical formwork is determined by the lateral pressure exerted by the fresh concrete, which in turn is determined by the mobility characteristics of the concrete and the method of consolidating the concrete. Research (ACI Committee 622 1957, 1958; Gardner and Ho 1979; Gardner 1980, 1981, 1985; Clear and Harrison 1985; Johnston et al. 1989; British Cement Association 1992; Dunston et al. 1994; Barnes and Johnston 1999, 2003) has assisted in developing recommendations for lateral pressures of conventional concrete.

Methods of consolidating concrete include rodding or spading (no longer used or recommended for large placements), internal vibration, and external vibration. The intensity and depth of internal vibration affect the lateral pressure exerted by vibrated concrete. Often, chemical admixtures are used in conventional concrete to facilitate consolidation.

In recent years, concrete technology has evolved with the use of supplemental cementitious materials and specialty chemical admixtures. Conventional concrete with slump values less than 9 in. (225 mm) are typically vibrated to ensure proper consolidation. With the increase in slump beyond 9 in. (225 mm), it is preferable to determine the slump flow spread of the concrete (ASTM C1611/C1611M) rather than slump. Concrete mixtures with slump flow spread between 15 and 24 in. (400 and 605 mm) may need vibration to consolidate satisfactorily; this depends on the placement conditions and characteristics of the structural element. Self-consolidating concrete (SCC) is a class of high-performance concrete that can consolidate under its own mass. Such concrete can be placed from the top of the formwork or can be pumped from the base without mechanical consolidation (ACI 237R).

The lateral pressure of concrete in formwork can be represented as shown in Fig. 4.2.2. Unless the conditions of 4.2.2.1 for conventional concrete or 4.2.2.2 for SCC are met, formwork should be designed for the hydrostatic pressure of the newly placed concrete given in Eq. (4.2.2.1a).

When working with mixtures using newly introduced admixtures that increase set time or increase slump characteristics, Eq. (4.2.2.1a) should be used until the effect on formwork pressure is understood by testing, measurement, or both.

4.2.2.1a Inch-pound version—The lateral pressure of concrete, C_{CP} (lb/ft²), can be determined in accordance with the appropriate equation listed in Table 4.2.2.1a(a).

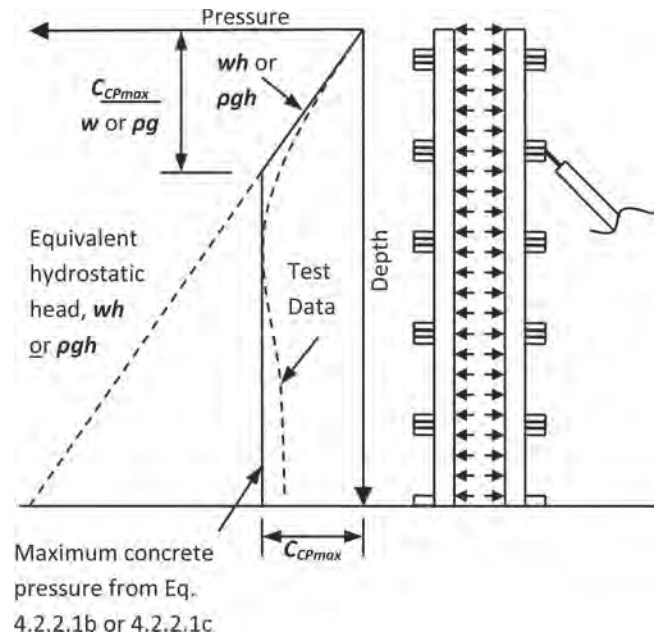


Fig. 4.2.2—Concrete lateral pressure distribution.

$$C_{CP} = wh \quad (4.2.2.1a(a))$$

$$C_{CPmax} = C_c C_w \left[150 + \frac{9000R}{T} \right] \quad (4.2.2.1a(b))$$

with a minimum of $600C_w$ lb/ft², but in no case greater than wh

$$C_{CPmax} = \left[150 + \frac{43,400}{T} + \frac{2800R}{T} \right] \quad (4.2.2.1a(c))$$

with a minimum of $600C_w$ lb/ft², but in no case greater than wh , where C_c is defined in Table 4.2.2.1a(b) and C_w is defined in Table 4.2.2.1a(c).

4.2.2.1b SI version—The lateral pressure of concrete, C_{CP} (kPa), can be determined in accordance with the appropriate equation listed in Table 4.2.2.1b.

$$C_{CP} = pgh \quad (4.2.2.1b(a))$$

$$C_{CPmax} = C_c C_w \left[7.2 + \frac{785R}{T + 17.8} \right] \quad (4.2.2.1b(b))$$

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

$$C_{CPmax} = C_c C_w \left[7.2 + \frac{1156}{T + 17.8} + \frac{244R}{T + 17.8} \right] \quad (4.2.2.1b(c))$$

with a minimum of $30C_w$ kPa, but in no case greater than pgh , where C_c is defined in Table 4.2.2.1a(b) and C_w is defined in Table 4.2.2.1a(c).

Table 4.2.2.1a(a)—Applicable lateral pressure equations for concrete other than SCC

Slump*	Internal vibration depth	Element	Rate of placement	Pressure equation
Greater than 7 in.	Any	Any	Any	4.2.2.1a(a)
Less than or equal to 7 in.	Greater than 4 ft	Any	Any	4.2.2.1a(a)
Less than or equal to 7 in.	Less than or equal to 4 ft	Column†	Any	4.2.2.1a(b)
		Wall‡ less than or equal to 14 ft tall	Less than 7 ft/h	4.2.2.1a(b)
		Wall‡ greater than 14 ft tall	Less than 7 ft/h	4.2.2.1a(c)
		Wall‡	7 to 15 ft/h	4.2.2.1a(c)
			Greater than 15 ft/h	4.2.2.1a(a)

*Slump for determination of lateral pressure shall be measured after the addition of all admixtures.

†For the purpose of this document, columns are defined as vertical elements with no plan dimension exceeding 6.5 ft.

‡For the purpose of this document, walls are defined as vertical elements with at least one plan dimension exceeding 6.5 ft.

Table 4.2.2.1a(b)—Chemistry coefficient C_c

Cement type	Slag	Fly ash	Retarders*	C_c
I, II, or III	None	None	None	1.0
			Included	1.2
Any	Less than 70 percent	Less than 40 percent	None	1.2
			Included	1.4
	Greater than or equal to 70 percent	Greater than or equal to 40 percent	None	1.4
			Included	1.5

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

Table 4.2.2.1a(c)—Unit weight coefficient C_w

Inch-pound version		SI version	
Unit weight of concrete, lb/ft ³	C_w	Density of concrete, kg/m ³	C_w
$w < 140$	$0.5[1 + (w/145 \text{ lb/ft}^3)]$ but not less than 0.80	$\rho < 2240$	$0.5[1 + (w/2320 \text{ kg/m}^3)]$ but not less than 0.80
$140 \leq w \leq 150$	1.0	$2240 \leq \rho \leq 2400$	1.0
$w > 150$	$w/145 \text{ lb/ft}^3$	$\rho > 2400$	$w/2320 \text{ kg/m}^3$

Table 4.2.2.1b—Applicable lateral pressure equations for concrete other than SCC

Slump*	Internal vibration depth	Element	Rate of placement	Pressure equation
Greater than 175 mm	Any	Any	Any	4.2.2.1b(a)
Less than or equal to 175 mm	Greater than 1.2 m	Any	Any	4.2.2.1b(a)
Less than or equal to 175 mm	Less than or equal to 1.2 m	Column†	Any	4.2.2.1b(b)
		Wall‡ less than or equal to 4.2 m tall	Less than 2.1 m/h	4.2.2.1b(b)
		Wall‡ greater than 4.2 m tall	Less than 2.1 m/h	4.2.2.1b(c)
		Wall‡	2.1 to 4.5 m/h	4.2.2.1b(c)
			Greater than 4.5 m/h	4.2.2.1b(a)

*Slump for determination of lateral pressure shall be measured after the addition of all admixtures.

†For the purpose of this document, columns are defined as vertical elements with no plan dimension exceeding 2 m.

‡For the purpose of this document, walls are defined as vertical elements with at least one plan dimension exceeding 2 m.

4.2.2.2 When working with self-consolidating concrete, the lateral pressure for design should be the full liquid head unless the effect on formwork pressure is understood by measurement or prior studies and experience. The lateral pressures developed by SCC are determined by considering the rate of concrete placement relative to the rate of development of concrete stiffness/strength. Any method has to include a measure of the stiffening characteristics of the SCC and should be capable of being easily checked using

on-site measurements. Often, laboratory tests are needed as a precursor to on-site monitoring tests. Several methods for estimating lateral pressure of nonvibrated SCC have been proposed (Gardner et al. 2012; Khayat and Omran 2011; Lange et al. 2008; DIN 18218:2010-01; “DIN Standard on Formwork Pressures Updated” 2010; Proske and Graubner 2008) and continue to be developed as additional data become available. Experience with these methods is presently somewhat limited. Thus, evaluation of estimated pressure on the

basis of more than one method is advisable until satisfactory performance is confirmed for the range of parameters associated with the project. Measuring pressures during placement and adjusting the rate of placement to control pressures within the capacity of the forms can be a wise precaution when using unproven SCC mixtures. Researchers and contractors have used pressure cells inserted through the form face and load cells on form ties with pressure based on tributary area as methods of measurement (Johnston 2010).

SCC placement pressures have the potential to reach full liquid head pressures. Generally, concrete lateral pressures will not reach full equivalent liquid head pressure but agitation of the already-placed concrete in the form will cause form pressure to increase. There are site and placement conditions that will increase form pressure. Site conditions that can transmit vibrations to the freshly-placed concrete can cause it to lose its internal structure and reliquefy. Heavy equipment operating close to the forms, or continued work on the forms, will transmit vibration. Dropping concrete from the pump hose or placing bucket will also agitate the in-place concrete. Concrete pumped into the bottom of a form will always create pressures higher than full liquid head.

4.2.2.3 Alternatively, a method for either conventional or self-consolidating concrete based on appropriate experimental data can be used to determine the lateral pressure used for form design (Gardner and Ho 1979; Gardner 1980, 1985; Clear and Harrison 1985; British Cement Association 1992; Dunston et al. 1994; Barnes and Johnston 1999, 2003) or a project-specific procedure can be implemented to control field-measured pressures in instrumented forms to the maximum pressure for which the form was designed (Johnston 2010).

4.2.2.4 If concrete is pumped from the base of the form, the form should be designed for full hydrostatic head of concrete wh (or ρgh) plus a minimum allowance of 25 percent for pump surge pressure. Pressures can be as high as the face pressure of the pump piston; thus, pressure should be monitored and controlled so that the design pressure is not exceeded.

4.2.2.5 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.

4.2.2.6 For slipform lateral pressures, refer to 9.2.2.4.

4.2.3 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.

4.2.3.1 Formwork exposed to the elements should be designed for wind pressures determined in accordance with ASCE/SEI 7 with adjustment as provided in ASCE/SEI 37 for shorter recurrence interval. Alternately, formwork may be designed for the local building code-required lateral wind

pressure but not less than 15 lb/ft² (0.72 kPa). Consideration should be given to possible wind uplift on the formwork.

4.2.3.2 For elevated floor formwork, the applied 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 produce effects not less than the effect of 100 lb/linear ft (1.5 kN/m) of floor edge or 2 percent of total dead load on the form distributed as a uniform load per linear foot (meter) of slab edge, whichever is greater.

4.2.3.3. For wall and column form bracing design, the applied value of horizontal load due to wind and eccentric vertical loads should produce effects not less than the effect of 100 lb/linear ft (1.5 kN/m) of wall length or column width, applied at the top.

4.2.3.4 Formwork in hurricane-prone regions should be given special consideration in accordance with ASCE/SEI 37.

4.2.4 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 from concrete pressure, uplift from wind, 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 5.8 for special conditions pertaining to multistory work.

4.2.5 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.

4.3—Member capacities

Member capacities for use in the design of formwork, exclusive of accessories, are determined by the applicable codes or specifications listed in Chapter 6. When fabricated formwork, shoring, or scaffolding units are used, manufacturer's recommendations for working capacities should be followed if supported by engineering calculations or test reports of a qualified and recognized testing agency. The effects of cumulative load duration should be considered in accordance with the applicable design specification for the material.

4.4—Safety factors for accessories

Table 4.4 shows recommended minimum factors of safety, based on committee and industry experience, 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 compared to the unfactored load. When manufacturer's recommended factors of safety are greater, the manufacturers recommended working capacities should be used.

Table 4.4—Minimum safety factors of formwork accessories

Accessory	Safety factor*	Type of construction†
Form tie	2.0	All applications
Form anchor	2.0	Formwork anchors supporting form weight, concrete pressures and wind load only
	3.0	Formwork anchors supporting form weight, concrete pressures, wind loads, construction personnel 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.

†Higher factors of safety are required by OSHA 1926 for work platform accessories.

4.5—Shores

Shores and reshores or backshores should be designed to carry all loads transmitted to them. A rational analysis (ACI 347.2R and ACI SP-4) 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:

- a) 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.
- b) Dead load weight of the concrete and formwork
- c) Construction live loads, such as the placing crews and equipment or stored materials
- d) Specified design strength of concrete
- e) Cycle time between the placement of successive floors
- f) Strength of concrete at the time it is required to support shoring loads from above
- g) 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 (Grundy and Kabaila 1963; Agarwal and Gardner 1974; Stivaros and Halvorsen 1990)
- h) Span of slab or structural member between permanent supports
- i) Type of formwork systems, that is, span of horizontal formwork components and individual shore loads
- j) Minimum age of concrete when creep deflection is a concern
- k) Loads applied due to post-tensioning transfer

Commercially available load cells can be placed under selected shores to monitor actual shore loads to guide the shoring and reshoring during construction (Noble 1975).

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.

4.6—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 is the unsupported length and r is the least radius of gyration. The braced system should be anchored to ensure stability of the total system.

4.7—Foundations for formwork

Proper foundations on ground, such as mudsills, spread footings, or pile footings, should be provided. Formwork footings and bracing anchors should be designed to resist the loads imposed without exceeding the allowable soil bearing capacity, without incurring excessive settlements affecting the formwork structural integrity and stability, and without deviating from the specified concrete elevation. 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. Mudsills should be protected from loss of soil bearing strength. Causes might include scour due to running water, nearby excavations, or the increase of moisture content caused by the supporting soil becoming wet or saturated. No concrete should be placed on formwork supported on frozen ground.

4.8—Settlement

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

CHAPTER 5—CONSTRUCTION

5.1—Safety precautions

Formwork engineers and formwork 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 workers 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-supporting. 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 structural elements that are used to support formwork and other construction loads. Note that the strength of newly completed structural elements will be less than their final design strength.

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 help prevent 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 include:

- a) Erection of safety signs and barricades to keep unauthorized personnel clear of areas in which erection, concrete placing, or stripping is under way
- b) Providing experienced formwork personnel with direct communication means to the placing crew, to closely watch during concrete placement to ensure early recognition of possible form displacement or potential failures; a supply of extra shores or other material and equipment that might be needed in an emergency should be readily available
- c) Provision for adequate illumination of the formwork and work area
- d) Inclusion of lifting points in the design and detailing of all forms that will be hoisted by cranes or other lifting equipment. 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 adequately fastened to the previous lift
- e) Incorporation of scaffolds, working platforms, and guardrails into formwork design and all formwork drawings
- f) Incorporation of provisions for anchorage of fall protection devices, such as personal fall arrest systems, safety net systems, and personnel positioning device systems

g) A program of field safety inspections of formwork

5.1.1 Formwork construction deficiencies—Some common construction deficiencies that can lead to formwork failures include:

- a) An ineffective inspection process for removing damaged or worn material(s), accessories, or other forming equipment having lower strength than required
- b) Insufficient nailing, bolting, welding, or fastening
- c) Insufficient or improper lateral bracing

d) Failure to comply with manufacturer's recommendations

e) Failure to construct formwork in accordance with the form drawings

f) Failure to obtain formwork engineer's approval for field modifications

g) Lack of proper prepour field inspection by competent persons to ensure that form design has been properly interpreted by form builders

h) Failure to inspect formwork during and after concrete placement to detect abnormal deflections or other signs of imminent or potential failure that should be corrected

5.1.1.1 Examples of deficiencies in vertical formwork—Construction deficiencies sometimes found in vertical formwork include:

a) Failure to control rate of placement of concrete without regard to design parameters

b) Inadequately tightened or secured form ties or hardware

c) Form damage in excavations resulting from embankment failure

d) Use of external vibrators on forms not designed for their use

e) Deep vibrator penetration of earlier semi-hardened lifts

f) Improper framing of blockouts

g) Improperly located or constructed pouring pockets

h) Inadequately supported bulkheads or construction joint formwork

i) Improperly anchored top forms on a sloping face

j) Failure to assess and control concrete properties and admixture effects with respect to concrete lateral pressure

k) Failure to provide adequate support for lateral pressures on formwork

l) Failure to recognize and resolve forces at locations in the formwork where lateral pressure is not resisted by form ties, such as at T-intersections of walls and at outside corners

m) Installation of lateral bracing at steeper angles than designed, resulting in an inability to maintain lateral stability, plumb, and alignment of the formwork

n) Placing concrete in such a manner that unbalanced forces are applied to wall opening blockouts, causing deflection or displacement of the breakout form

o) Failure to provide adequate bracing resulting in attempts to plumb forms against concrete weight, wind loads, or other horizontal forces

p) Inadequately supported wall form or column form panels

q) Inadequate fastening of the form to previous concrete placement or foundation

5.1.1.2 Examples of deficiencies in horizontal formwork—Construction deficiencies sometimes found in horizontal forms for elevated structures include:

a) Failure to properly regulate the sequence of placing concrete to avoid unanticipated loadings on the formwork

b) Shoring not plumb, thus inducing lateral loading and reducing vertical load capacity

c) Locking devices on metal shoring not locked, inoperative, or missing. Safety nails missing on adjustable two-piece wood shores

d) Failure to account for vibration from adjacent moving loads or load carriers

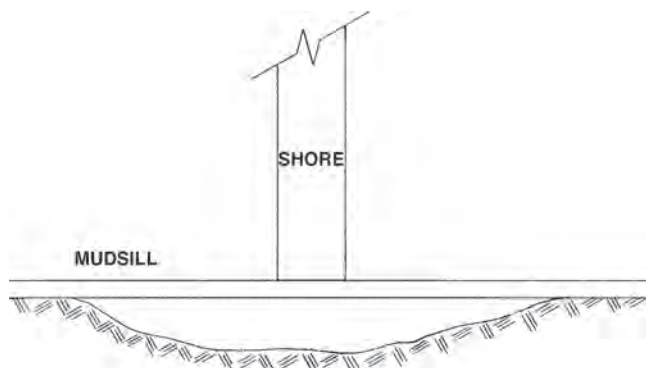


Fig. 5.1.1.2a—Inadequate bearing under mudsill.

- e) Inadequately tightened or secured shores and reshores including hardware or wedges
- f) Loosening or premature removal of reshores or backshores under floors below
- g) Premature removal of supports, especially under cantilevered sections
- h) Inadequate bearing area or unsuitable soil under mudsills (Fig. 5.1.1.2a)
- i) Mudsills placed on frozen ground subject to thawing or on saturated ground; mudsills placed prior to a large rain event during which water accumulates and washes the soil out from under the sill
- j) Connection of shores to joists, stringers, or wales that are inadequate to resist uplift or torsion at joints (refer to Fig. 5.1.1.2b)
- k) Failure to consider effects of load transfer that can occur during post-tensioning (refer to 5.8.6)
- l) Failure to perform, document, and follow up on preplacement formwork inspections
- m) Kinked, bent, or otherwise damaged shoring equipment
- n) Inadequate shoring and bracing of composite construction
- o) Inadequate bracing for horizontal loads due to wind or other horizontal forces

5.2—Construction practices and workmanship

5.2.1 Fabrication and assembly details—The following are examples of good construction practice:

- a) Properly spliced studs, wales, strongbacks, shores, and other members of two or more pieces.
- b) Shores should be installed plumb within the allowable tolerance and with adequate bearing and bracing.
- c) Specified size and capacity of form ties or clamps should be used.
- d) 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.
- e) Forms should be sufficiently tight to minimize loss of mortar from the concrete.
- f) Pour windows or pockets may be necessary in wall forms or other high, narrow forms to facilitate concrete placement and vibration.

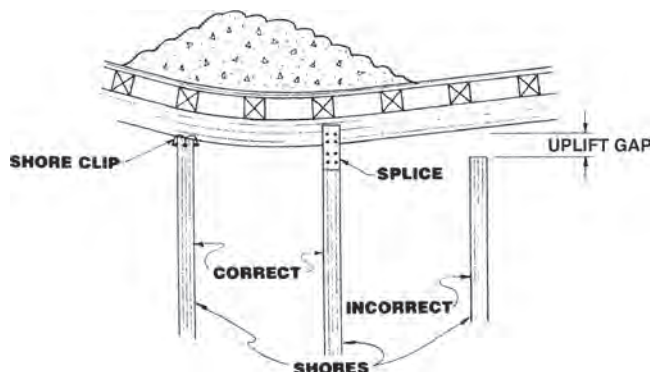


Fig. 5.1.1.2b—Uplift of formwork. Connection of shores to joists and stringers should hold shores in place when uplift or torsion occurs.

g) Fabricate ganged formwork, tables, and column forms on a suitable platform, horses, or other means of support to assure correct and square geometry, straight formwork edges, and the absence of built-in warp within tolerances.

5.2.2 Joints in concrete

5.2.2.1 Contraction joints, expansion joints, control joints, construction joints, and isolation joints should be installed as specified in the contract documents (Fig. 5.2.2.1) or as requested by the contractor and approved by the engineer/architect.

5.2.2.2 Bulkheads for construction joints should preferably be made by splitting the sheathing along the lines of the reinforcement (either vertically or horizontally) passing through the bulkhead, and installing the supports such that the sheathing material is supported along these cuts and is supported frequently enough to limit its deflection. Construction joint formwork should be made in such sizes so that it is not trapped behind the reinforcing steel. By doing this, the formwork can be removed more easily and, in some cases, reused.

5.2.2.3 When required by the contract documents, beveled inserts at control or contraction joints should be left undisturbed when forms are stripped, and then removed only after the concrete has been sufficiently cured.

5.2.2.4 Wider wood feature strips, reveals, or rustications inserted for architectural treatment can be kerfed on their back sides so as to allow for expansion to take place in the wooden piece as a result of moisture absorption.

5.2.3 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.

5.2.4 Formwork inspection—The inspection should be performed by a person certified as an ACI Concrete Construction Special Inspector or a person having equivalent formwork training and knowledge.

a) Formwork should be inspected for compliance with the formwork drawings.

b) 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.

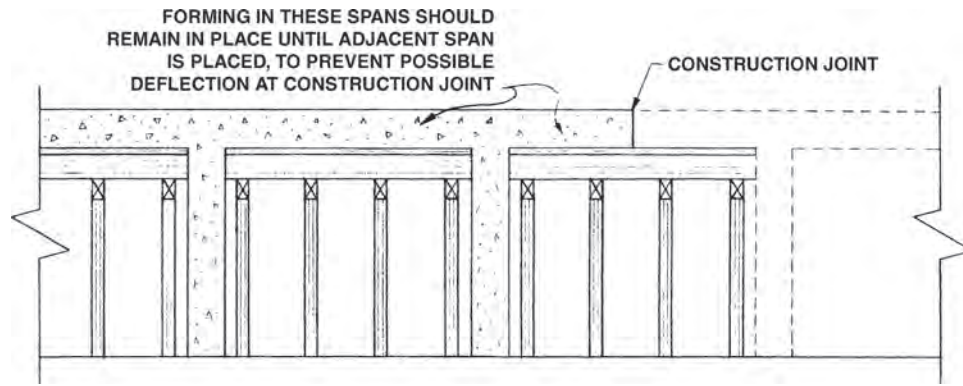


Fig. 5.2.2.1—Forming and shoring restraints at construction joints in supported slabs.

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

d) Formwork should be checked for required camber when specified in the contract documents or shown on the formwork drawings. Formwork camber should be measured after casting but before post-tensioning and stripping of shores. Permanent camber should be measured at soffit both before and after stripping.

5.2.5 Cleanup and coatings—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 of the concrete is important, forms should not be reused if damage from previous use would cause impairment to concrete surfaces.

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

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

5.2.7 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.

5.3—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**.

Table 5.3.1—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)

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

5.3.1 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. It should be noted that tolerances normally found in construction specifications, such as those in ACI 117, are for the as-built concrete members and not the formwork used to shape these members. Formwork should be constructed with such dimensions so the resulting concrete members are within the specified dimensional tolerances.

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 D surface (Table 5.3.1) is incompatible with most concrete one-way (lap pans) joist construction techniques. As a matter of practical construction, lap pans will not provide Class D in all cases, particularly when subject to reuse on a project.

Where a project involves features sensitive to the cumulative effect of tolerances on 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 which tolerance 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.

5.4—Irregularities in formed surfaces

ACI 347.3R provides detailed guidance and methods for producing and evaluating concrete formed surfaces. This section provides a summary of ways of evaluating surface variations due to forming quality but is not intended for evaluation of surface defects, such as surface voids (bugholes and blowholes), and honeycomb attributable to placing and consolidation deficiencies. These are more fully explained by ACI 347.3R and **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 of plane surfaces, the straightedge can be placed anywhere on the surface in any direction.

Four classes of formed surface are defined in **ACI 117-10**, 4.8.3 (Table 5.3.1). 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 301-10**, 5.3.3.3, with form-facing materials meeting the requirements of ACI 301-10, 2.2.1.1, 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.

Construction methods such as using metal form pans provide a finish unique to itself and should be given special consideration by the engineer/architect. 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 5.3.1, they should be specified by the engineer/architect.

5.5—Shoring and centering

5.5.1 Shoring—The design process and construction practices should be in accordance with **ACI 347.2R**. Shoring should be supported on satisfactory foundations, such as spread footings, mudsills, slabs-on-ground, piers, caissons, or piling, as discussed in 4.7.

Shores 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 moments and punching shear. The reversal of bending moments in the slab over the shore or reshore below may occur as shown in Fig. 5.5.1a. If reshores do not align with the shores above, then calculate for reversal of moments. Generally, the moment induced by the slab dead loads will not be reversed by the effect of having the upper shore offset in location from the reshore below. Reshores should be prevented from falling by such means as spring clips at the top of reshores and positively attaching perimeter reshores back into the interior of the structure with appropriate lacing or bracing. The reshoring plan should be submitted to the engineer/architect for review related to effects on permanent structures. Multi-tier shoring—single-post shoring in two or more tiers—is a dangerous practice and is not recommended (refer to Fig. 5.5.1b).

Where a slab load is supported on one side of the beam only (refer to Fig. 4.1.4), edge beam forms should be carefully planned to prevent rotating of the beam side form due to unequal loading. All members should be straight and true without twists or bends. Special attention should be given to beam and slab construction or one- and two-way joist construction to prevent local overloading when a heavily loaded shore rests on a thin slab.

Vertical shores should be erected so that they cannot tilt and should have a firm bearing. Inclined shores should be braced securely against slipping, sliding, or buckling. The bearing ends of shores should be square to the supported member. Wedges may be cut and installed to achieve full bearing on sloped surfaces or with inclined support members. 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. 5.1.1.2b).

5.5.2 Centering—When centering is used, lowering is generally accomplished by the use of sand jacks, 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 8.4.

5.6—Inspection and adjustment of formwork

Helpful information about forms before, during, and after concrete placement can be found in **ACI SP-2**, **ACI SP-4**, and **ACI 311.4R**.

5.6.1 Before concrete placement—Telltale devices should be installed on shores or forms to detect formwork movements during concrete placement and wedges used for final

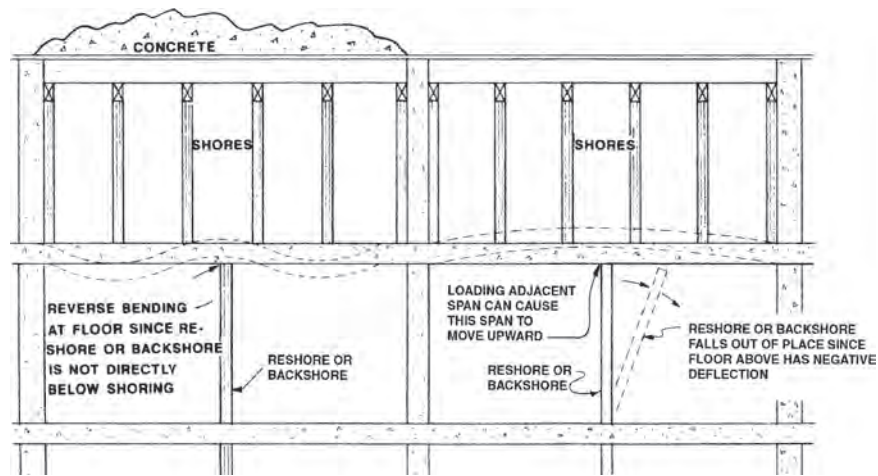


Fig. 5.5.1a—Reshore installation. Improper positioning of shore from floor to floor can create bending stresses for which the slab was not designed.

alignment before concrete placement should be secured in position before the final check.

Formwork should be anchored to the shores below so that undesired movement of any part of the formwork system will be prevented during concrete placement. Such anchorages should be installed in such a way as to allow for anticipated take-up, settlement, or deflection of the formwork members.

Additional height 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. Where appropriate, the dimensional value of the expected shortening effects may be stated in the formwork design drawings.

Positive means of adjustment (wedges or jacks) should be provided to permit realignment or readjustment of shores if settlement occurs. Adjustment during or after concrete placement should not be performed.

5.6.2 During and after concrete placement—During and after concrete placement, but before initial set of the concrete, the elevations, camber, and plumbness of formwork systems should be checked using telltale devices. This information is useful for the next time the forms are used in a similar configuration. 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 the placing crews in case of emergency.

Some corrections that may be possible are stopping excess leakage, slowing the rate of pour for vertical members that show signs of distress, adding ties or bracing from the outside of bulging forms, tightening bracing, adding bracing, and adding shores to prevent additional deflection.

5.7—Removal of forms and supports

5.7.1 Discussion—Although the contractor is generally responsible for design, construction, and safety of formwork, concrete strength, age criteria, or all, for removal of forms or shores should be specified by the engineer/architect. The formwork engineer/contractor should communicate specific

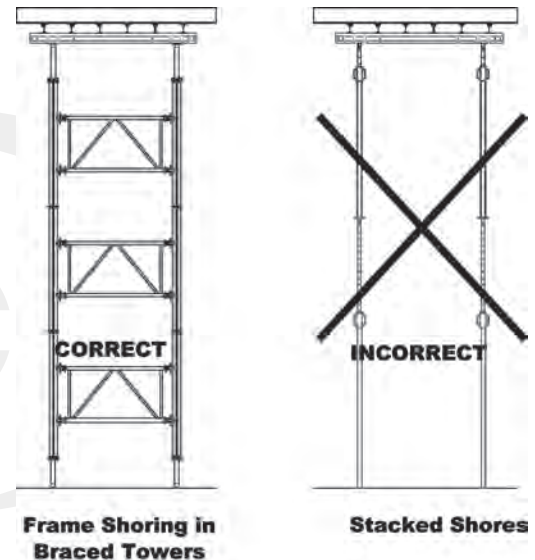


Fig. 5.5.1b—Tall shoring should be fully braced; stacked single shores in two or more tiers is dangerous.

sequences of erection and removal of shoring and reshoring on the formwork drawings.

5.7.2 Recommendations

5.7.2.1 The engineer/architect should specify the minimum strength of the concrete that should be reached before removal of forms or shores. The strength can be determined by tests on field-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, 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 perform the tests. Results of such tests, including such values as cylinder compressive strength, cylinder size, and cylinder weight, as well as records of weather conditions and other pertinent information should be recorded by the contractor or the person

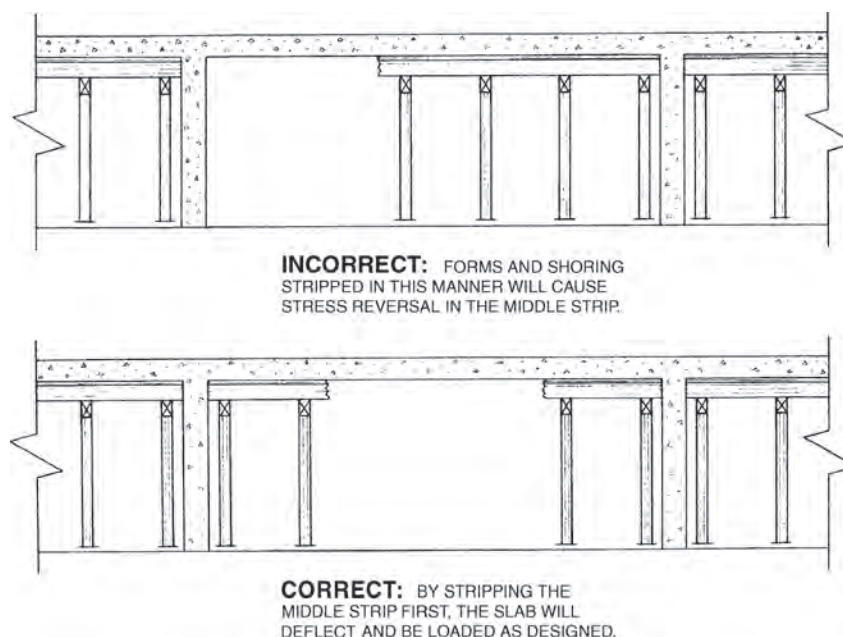


Fig. 5.7.2.1—Stripping sequence for two-way slabs.

designated in the contract documents. It should be clearly stated if a minimum time after placement is a requirement to strip forms in addition to the normal minimum compressive strength requirement.

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. 5.7.2.1). If 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 stripping strength specified by the engineer/architect. Shores supporting post-tensioned construction should not be removed until sufficient tensioning force is applied to support the dead load, formwork, and anticipated construction loads.

As a general rule, the vertical forms for columns, walls, beam sides, and piers can be removed before horizontal forms for beams and slabs. Formwork and shoring should be constructed so that 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.

5.7.2.2 The removal of forms, supports, and protective enclosures, and the discontinuation 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 that the test specimens repre-

sent. The temperature of the concrete while curing, not the ambient air temperature, is an important factor in the strength gain of concrete. The curing time and concrete temperature records can serve as a basis to assist the engineer/architect with review or approval of form stripping.

5.7.2.3 Because the minimum stripping time is usually a function of concrete strength, the preferred method of determining stripping time is a comparison of the actual strength gained to the strength required for stripping the element. Walls, columns, and beam sides can usually be stripped at fairly low concrete strengths. Soffits of slabs, beams, and other elevated work need greater strength to be self-supporting and carry imposed construction loads. **ACI 301** lists tests of job-cured cylinders, several tests of concrete in place, and evaluation by the maturity method as acceptable methods of determining field strength. When the contract documents do not specify the minimum concrete strength required at the time of stripping, the engineer/architect should be consulted and methods discussed in ACI 301 should be used for determining appropriate form removal criteria. The elapsed times shown in Table 5.7.2.3 may be used as guidance for determining stripping time for general planning purposes. 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 the time of stripping. It is important to note that the temperature of the concrete is the key to strength gain,

Table 5.7.2.3—Guidance for stripping time when contract documents do not specify stripping time or stripping strength required

Structural element supported	Structural live load not greater than structural dead load	Structural live load greater than structural dead load
Walls*	12 hours	12 hours
Columns*	12 hours	12 hours
Sides of beams and girder*	12 hours	12 hours
Pan joist forms†		
30 in. (760 mm) wide or less	3 days	3 days
Over 30 in. (760 mm) wide	4 days	4 days
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 placement of reshores where required. Reshores should be 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 5.8), 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 post-tensioning operations have been completed and approved	

*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.

§Refer to Section 5.8 for special conditions affecting the number of floors to remain shored or reshored.

not the ambient air temperature. Ambient air temperature is only used in this case to show a minimum ambient air temperature that will still allow concrete temperatures to be adequate for proper cement hydration. Concrete temperature inside forms can vary depending on the type of forms used and any methods that are employed to reduce heat loss from unformed surfaces, such as the top of a wall or top of a slab. **ACI 305R** and **ACI 306R** provide further discussion of how ambient air temperature affects concrete strength gain.

5.8—Shoring and reshoring of multistory structures

This section discusses methods of shoring and reshoring of multistory structures and provides general guidance and considerations. **ACI 347.2R** expands on these concepts and should be consulted for further guidance on shoring and reshoring practices.

5.8.1 Discussion—Shores or falsework are vertical or inclined support members designed to carry the weight of formwork, concrete, and construction loads, and reshores are shores placed snugly under a stripped concrete slab or structural member after the original forms and shores have been removed from at least full bays. This requires the new 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 presents 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 concrete placement 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 should 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 (**Grundy and Kabaila 1963**; **Agarwal and Gardner 1974**; **Stivaros and Halvorsen 1990**). Reshoring is used to distribute construction loads to the lower floors.

In a common method of analysis (**ACI 347.2R**; **ACI SP-4**), 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 be exercised when a compressible wood shoring 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.

5.8.2 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.

If prefabricated drop-head shores are used, the shores can become the reshores if a large area of shoring is unloaded, permitting the structural members to deflect and support their own weight. The drop-head shore has a head that can be lowered to remove forming components without removing the shore or changing its support for the floor system. Later the shore may be retracted and resnugged to act as a reshore. It can also be used as a backshore or preshore.

5.8.3 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. 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. 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.

5.8.4 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 capacity, 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 of the completed structure 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 anticipated loads.

Where practical, shores should be located in the same position on each floor so that there will be continuous 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 exercised 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 it has been determined by the formwork engineer/contractor that 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.

5.8.5 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. Shores should be removed or released before reshore removal. Premature reshore removal can be dangerous as it can result in overloading the slabs above. Removal operations should be carried out in accordance with a planned sequence so that the structure supported is not subject to impact or nonsymmetric load patterns.

5.8.6 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 generally produces a downward load at the beam. If the beam is shored, the shoring should be designed to carry this added load. The magnitude of the load can approach the dead load of half 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. Additionally, special attention should be given to locations where a post-tensioned beam intersects a post-tensioned girder with no column at the intersection. Post-tensioning forces at these points due to accumulated dead load transfer can be substantial and should be accounted for in the reshoring design. Similar load transfer situations occur in post-tensioned bridge construction.

CHAPTER 6—MATERIALS

6.1—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 form-

work 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 define their expectations in the contract documents and reference specific locations where the critical appearance(s) applies. Refer to Chapter 7 for architectural concrete provisions.

6.2—Properties of materials

6.2.1 General—ACI SP-4, *Formwork for Concrete*, 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 6.2.1 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.

6.2.2 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, plastic, or other materials capable of transferring imposed construction loads 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 (ACI 347.3R).

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

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

6.2.3 Structural supports—Structural support systems should meet material strength requirements to carry the imposed construction loads that have been transferred through the sheathing.

Important considerations include:

- a) Strength
- b) Stiffness
- c) Dimensional accuracy and stability
- d) Workability for cutting, drilling, and attaching fasteners
- e) Weight
- f) Cost and durability
- g) Ability to accommodate required contours and shapes

6.3—Accessories

6.3.1 Form ties—A form tie is a tensile device used to hold concrete forms against spreading apart due to the lateral pressure of concrete. In general, it consists of an inside tensile member and external holding devices. Form ties are made to a range of specifications, depending on the manufacturer. These manufacturers also publish recommended working loads on ties for use in form design. Their suggested working loads range from 1000 to more than 50,000 lb (4.45 to 222.40 kN). Manufacturers produce numerous types of ties for different forming conditions. Refer to ACI SP-4 for a description of commonly available tie systems.

6.3.2 Form anchors—Form anchors are devices used to secure formwork to previously placed concrete of adequate strength. The devices are normally embedded in a previous concrete placement or drilled in or fastened to a previous concrete placement or other suitable structural member. 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. When anchoring to other elements, whether concrete, timber lagging, sheet piling, or H-piles, consideration should be given to effects of the loads transferred to those elements. Manufacturers publish design data and test information to assist in the selection of proper form anchor devices.

6.3.3 Form hangers—Form hangers are devices used to suspend formwork loads from structural steel, precast concrete, or other members. They may be fabricated from wire, flat metal pieces, plastic, or combinations of these materials.

6.3.4 Reinforcing bar spacers—A reinforcing bar spacer is a device that maintains the desired distance between a form and an internal embedded or encased element. Horizontal reinforcing bar spacers are used as reinforcing bar supports. Both factory-made and job-site-fabricated devices have been successfully used. Advantages and disadvantages of the different types are explained in ACI SP-4 and in **CRSI (2009)** and **Randall and Courtois (1976)**. Consideration should be given to any environmental effects on the reinforcing bar spacer material, such as corrosion, and visibility on the exposed concrete surface. Spacers may affect the surface finish appearance of the concrete.

6.3.5 Recommendations—The recommended factors of safety for ties, anchors, and hangers are given in 4.4. The rod- or band-type form tie and a holding device engaging the exterior of the form, with a supplemental provision for maintaining the distance between form faces, is the most common type used for light construction.

The threaded internal disconnecting type of tie, taper ties, or sleeved through-rod (also called through tie) are often used for building construction as well as 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 should be

Table 6.2.1—Form materials with data sources for design and specification

Materials	Principal uses	Data sources
Sawn lumber	Form framing, sheathing, and shoring	PS20-10; U.S. Department of Agriculture (2010); American Wood Council (2012); ANSI/AWC NDS-2012; American Institute of Timber Construction (2012); Bryer et al. (2006)
Engineered wood*	Form framing and shoring	Smulski (1997); CSA-O86-M84
Plywood	Form sheathing and panels	PS1-09; APA D510; APA Y510; APA V345
Steel	Panel framing and bracing	AISC 325-11; AISI D100-08
	Heavy forms and falsework	
	Column and joist forms	ANSI A48.1; ANSI A48.2; CRSI (2009)
	Stay-in-place deck forms	ASTM A446
	Shoring	SH 304-00
	Steel joists used as horizontal shoring	SH 301-03
Aluminum [†]	Expanded metal bulkheads, single-sided forms	Steel Joist Institute (2010); Hurd (1997b)
	Form panels and form framing members	
Reconstituted wood panel products [‡]	Horizontal and vertical shoring and bracing	The Aluminum Association (2010)
	Form liners and sheathing	
Insulation materials: a) Wood fiber or glass fiber b) Other commercial products	Stay-in-place form liners or sheathing	ANSI A208.1; PS20-10
Fiber or laminated paper pressed tubes or forms	Cold-weather protection for fresh concrete	ACI SP-4
	Column and beam forms	
Corrugated cardboard	Void forms for slabs, beams, girders and precast piles	ACI SP-4
	Internal and under-slab void forms	
Concrete	Void forms in beams and girders (normally used with internal egg-crate stiffeners)	Ziverts (1964)
	Stay-in-place forms	
Glass fiber-reinforced plastic	Molds for precast units	ACI 318
	Ready-made column forms	
	Domes and pans for concrete joist construction	Hurd (1993, 1997a)
	Custom-made forms for special architectural effects	
	Form ties	
Cellular plastics	Form lining and insulation	ACI SP-4
	Stay-in-place wall forms	
Other plastics, including ABS, polypropylene, polyethylene, polyvinyl chloride, polyurethane	Form liners, both rigid and flexible, for decorative concrete	Hurd (1994)
	Chamfer and rustication formers	
Form ties, anchors, and hangers	Hold formwork secure against loads and pressures from concrete and construction activities	Safety factors recommended in 4.4; Hurd (1993)
Side form spacers	Maintain correct distance between reinforcement and form to provide specified concrete cover for steel	Randall and Courtois (1976)
Plaster	Waste molds for architectural concrete	ACI 303R; ACI SP-4
Release agents and protective form coatings	Help preserve form facing and facilitate release	Hurd (1996)

*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, it should be nonreactive to concrete or concrete containing calcium chloride.

[‡]Check surface reaction with wet concrete.

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 ACI SP-4 and in the references cited in Chapter 8 and Chapter 10 of this document.

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 the form members. It is important to minimize mortar leakage at form ties.

Form hangers should support all construction loads imposed on the formwork supported by the hangers. Form hangers should be symmetrically arranged on the supporting member and loaded symmetrically, through proper sequencing of 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 as per the manufacturer's instructions.

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. Noncorrosive materials should be used when tie holes are left unpatched, exposing the tie to possible corrosion.

6.4—Form coatings and release agents

6.4.1 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:

- a) Alter the texture of the contact surface
- b) Improve the durability of the contact surface
- c) Facilitate release from concrete during stripping
- d) Seal the contact surface of the form from intrusion of moisture

6.4.2 Release agents—Form release agents are applied to the form contact surfaces to prevent bond and thus facilitate stripping. They may be applied permanently to certain form materials during manufacture, but are normally applied to the form before each use. When applying in the field, be careful to avoid coating adjacent construction joint surfaces or reinforcing steel.

6.4.3 Manufacturers' recommendations—Manufacturers' recommendations should be followed in the use of coatings, sealers, and release agents. Independent verification of product 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. Follow the manufacturer recommendations when applying form release agents. A common problem is applying too much material, which can negatively affect the surface of the concrete.

to architectural concrete. Additional information is available in **ACI 301**, **ACI 303R**, and **ACI 347.3R**.

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

7.1.2 Factors affecting formwork—Architectural concrete is concrete that will be permanently exposed to view and therefore requires special care in the selection of the concrete materials, forming, placing, and finishing to obtain the desired architectural appearance. Architectural concrete should be 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 minimize mortar leakage.

7.1.3 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 surface appearance of 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 architectural concrete construction is quality workmanship.

7.1.4 Uniform construction procedures—Architectural concrete should minimize color variations and differences in surface finish. The best way for the contractor to achieve this uniformity is to maintain consistency in all construction practices. Forming materials should remain the same throughout the project, 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 consistent throughout the work to minimize color variations.

CHAPTER 7—ARCHITECTURAL CONCRETE

7.1—Introduction

7.1.1 Objective—The general requirements for formwork presented in preceding chapters for the most part also apply

7.2—Role of architect

7.2.1 Preplanning—Architectural concrete is often structural, but the formed concrete surface generally desired for architectural concrete is of a higher quality than what is typically satisfactory for structural concrete, and 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. Intricacies and irregularities, however, can raise the budget to a point that outweighs the aesthetic contributions of the architectural concrete. 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 and greater uniformity of appearance. A prebid conference with qualified contractors will bring out many practical considerations before the design is finalized.

7.2.2 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 7.2.3 to 7.2.7. 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 should be a requirement for all architectural concrete. Once such a mockup has been completed to the satisfaction of the architect and owner, it should remain 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 that can help define what is required for the mockup. Small samples like these, kept at the job site for reference, are not as good as a full-scale mockup, but can be helpful in defining mockup requirements. The samples should be large enough to adequately represent the surface of the concrete desired. The samples are to be used as a basis for the mockup only. Several should be made to represent the variations that can occur in the final finish. It would be helpful for all architectural concrete to include a required mockup so that the contractors can demonstrate they are capable of producing the desired results. The mockup should be approved in writing by the architect and owner.

It can be helpful to specify viewing conditions under which the concrete surfaces will be evaluated for compliance with the approved mockup.

7.2.3 Tolerances—The architect should specify dimensional tolerances considered essential to the successful execution of the design, keeping in mind that tolerances in excess of those specified in **ACI 117** need to be necessary, achievable, and economically feasible. **ACI 303R** and 117 may be consulted for further discussions concerning tolerances for architectural concrete.

7.2.4 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 hori-

zontal 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. Determining the correct amount of camber is not an exact science. If the calculated camber for a specific member does not result in its deflection to a straight line, the result will be a convex or concave concrete surface.

7.2.5 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 drawings 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 332.1R.) 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 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 surface voids (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 in beams and slabs, usually the middle third of the span.

7.2.6 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 7.3.4 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 and specify examples of the patches as part of the mockup.

7.2.7 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 control of required cover, the architect can specify appropriate side form spacers as defined in 6.3.4.

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.

7.3—Materials and accessories

7.3.1 Sheathing or form facing—Architectural concrete form sheathing should be of appropriate quality to maintain the specified uniformity of concrete surfaces through multiple uses and to control deflection within specified limits. Plywood, steel, glass fiber-reinforced plastic, aluminum, and other suitable materials can all be used 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 forms should be carefully followed.

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

7.3.3 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.

7.3.4 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 minimize leakage at the holes. If textured surfaces are to be formed, ties should be carefully evaluated with regard to fit, pattern, mortar leakage, and aesthetics.

7.3.5 Side form spacers—Side form spacers, as defined in 6.3.4, 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.

A contributing factor to reinforcing spacers being visible at exposed concrete surfaces is the amount of load that exists between the reinforcing steel, the spacer, and the form facing. If the reinforcing steel is installed plumb, straight, and with the correct spacing where it protrudes from previous castings, there should not be an extraordinary amount of force required between these elements and the spacer should be there only to prevent the reinforcing bar from being displaced during concrete placement operations. If, on the other hand, the formwork and spacers are being used to forcibly push the reinforcing bar into position, there is a chance that the legs of the spacers can leave imprints in the sheathing that will result in visible spacers. There is also a chance that the formwork itself can be distorted by these forces. With architectural formwork, it is advisable not to

start erecting or closing formwork until the reinforcing steel is in its correct location, in a relaxed state, so that it does not rely on the formwork to push it into correct position. Contractors are encouraged to experiment with different types of spacers for different exposed elements to determine which are best for the various applications on a project. The same spacers that will be used on the finished work should be incorporated in the mockup.

7.3.6 Reinforcing accessories and tie wire—Noncorrosive types of tie wire and accessories should be used for architectural concrete, especially when close to or in contact with the forms. Suitable materials include stainless steel, epoxy-coated material, or plastic-coated material; use of these items needs to be specified. Stainless steel is often the best choice as wire snippings often fall into the forms and are difficult to remove before placing concrete.

7.4—Design

7.4.1 Special considerations—The general design procedure will follow the principles outlined in Chapter 4. The formwork engineer/contractor, however, will frequently need to work with limitations imposed by the architectural design. Some of these considerations include 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.

7.4.2 Lateral pressure of concrete—Architectural concrete can be subjected to external vibration, revibration, set retarding admixtures, high-range water-reducing admixtures, and slumps greater than those assumed for determining the lateral pressure as noted in 4.2.2. Particular care should be exercised in these cases to design the forms for the increased lateral pressures that may result from these effects, high rates of pour, or from other effects noted in 4.2.2.

7.4.3 Structural considerations—Because deflections in the contact surface of the formwork directly influence the appearance of finished surfaces viewed under varying light conditions, forms for architectural concrete should be calculated and evaluated carefully to minimize deflections. In most cases, deflections govern design rather than bending (flexural stress) or 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 (refer to ACI 301 and ACI 303R). Forms bow with reuse; therefore, more bulging will occur in the formed surface after several uses of the same form. 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 limit deflections within the requirements of the project specification. Joints of sheathing materials should be backed with structural members to minimize offsets.

7.4.4 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 respect to 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 re-anchoring forms in preceding or adjacent placements to achieve a tight fit and minimize grout leakage at these points. Ties should be located as close as possible to the construction joint to facilitate re-anchoring the form to adjacent placements.

7.4.5 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 or back-fastened to the forms.

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

7.4.6 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.

7.5—Construction

7.5.1 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 minimize segregation, honeycomb, sanding, or cold joints in the concrete. It should be noted that if pour pockets are required on the forms for architectural concrete, they will normally leave a mark on the finished 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 or causing damage to the forms.

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 and cleaned after each use to ensure that they have not become damaged, distorted, disassembled, or otherwise unable to perform as designed.

7.5.2 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. Screws are often used to fasten the sheathing. Back fastening should be used if the imprints from nail or screw heads are objectionable.

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 minimize seepage of water and mortar between the form and previously placed concrete surfaces.

Architectural concrete forms should be designed to minimize water leakage and avoid discoloration. One method to minimize 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. Tight forms require more care during vibration to remove entrapped air that can cause surface voids (bugholes).

Textured surfaces on multi-lift construction should be separated with rustication strips or broad reveals because accumulation of construction tolerances, random textures, or both, prevents 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.

7.5.3 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 reinforcement. The form coating to be used should not stain the concrete or impair the adhesion of paints or other surface treatments and should be submitted to the architect for approval.

Form sealers should be tested to ensure that they will not adversely affect the texture when a form lining material is used.

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 completely removed.

7.5.4 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 sealing.

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 sealed. 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.

7.6—Form removal

7.6.1 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 as specified in the contract documents.

7.6.2 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.

7.6.3 Uniformity—To maximize 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. Ambient conditions and sunlight exposure can influence the eventual color of the concrete.

7.6.4 Avoiding thermal shock—Cold-weather concrete placement 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. It should be noted that it is the temperature of the concrete that is important to proper curing, not the ambient air temperature.

CHAPTER 8—SPECIAL STRUCTURES

8.1—Discussion

Formwork for all structures should be designed, constructed, and maintained in accordance with recommendations in Chapters 1 to 6. This chapter deals with the additional requirements for formwork for several special classes of work. **ACI 372R** and **373R** contain information on design and construction of circular prestressed-concrete structures.

8.2—Bridges and viaducts, including high piers

8.2.1 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.

8.2.2 Shoring and centering—Recommended practice in **5.5** and **5.7** 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 **5.8.6**.

8.2.3 Forms—Forms can be of any of a large number of materials but the most common 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.

8.3—Structures designed for composite action

8.3.1 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 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.

8.3.2 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 between shores posted to relatively unyielding supports, such as foundations, and shores posted to structures or members that are already elastically supported (refer to 5.8).

Composite construction can incorporate beams of relatively light cross sections that are fully adequate when construction is complete. During construction, however, these beams may require lateral support from the formwork. The engineer/architect should alert the contractor to this condition in general notes on the structural drawings or in notes on applicable drawings where this condition exists. The formwork engineer/contractor should be alert to this possibility and provide shoring or lateral support where needed.

8.3.3 Erection—Construction of permanent elements, erection of formwork, or both, for composite construction follows basic recommendations contained in Chapter 5. 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 concrete placement, 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 may be possible during or after placing, it is not recommended and may only be attempted prior to initial set of the concrete.

Where camber is required, a distinction should be made between the part that is an allowance for settlement or deflection of formwork or shoring and the portion of camber that 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 (refer to 3.2.5). 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.

8.3.4 Removal—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.

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

8.4.1 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 the engineer/architect's design.

8.4.2 Design—The following are items that should be included in the contract documents:

- a) The engineer/architect should specify limiting values and directions of the reactive forces when the falsework is supported by the permanent structure.
- b) 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.
- c) In determining the lateral forces acting on the formwork, the wind load should be calculated on the basis of a minimum of 15 lb/ft² (0.72 kPa) of projected vertical area as specified for wall forms in 4.2.3. For structures such as domes, negative forces due to suction created by the wind on the leeward side of the structure should be considered.
- d) The recommendations of 4.1.1 and 4.3 should be followed in formwork planning.

Formwork design loads should be shown on the formwork drawings. Complete stress analyses should be prepared by structural engineers experienced in these types of structures, 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 specified 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 should be specified by the engineer/architect in the bidding documents.

8.4.3 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 the type of inserts and joints in sheathing, where spreading of the form can result in the form becoming keyed into the concrete.

8.4.4 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.

8.4.5 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 by the formwork engineer/contractor and adhered to in the field.

8.4.6 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 so as to prevent unanticipated concentrated reactions on 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. Although required compressive strengths may already have been attained, moduli of elasticity can control time of decentering (refer

to [ACI 334.1R](#), 5.2.3). 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.

8.5—Mass concrete structures

8.5.1 Discussion—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: low lift and high lift. Low-lift formwork, for heights of 5 to 10 ft (1.5 to 3 m), usually consists of multi-use steel cantilever form units that incorporate their own work platforms and, on occasion, lifting devices. High-lift formwork is comparable to the single-use wood forms used extensively for structural concrete.

8.5.2 Lateral pressure of concrete—The lateral pressure formulas for concrete placed in walls can be used for mass concrete (refer to [4.2.2](#)). The formwork engineer needs to carefully review the concrete mixture proportion to determine the appropriate formula from 4.2.2. 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.

8.5.3 Design considerations—Mass concrete forming can require special form tie and anchor design. Forming sloping surfaces requires ties or anchors to resist pressures that are perpendicular to the face of the form. Therefore, only using horizontal ties will leave the vertical component of pressure untied. Vertical (hold-down) anchors should be used. 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. The formwork engineer/contractor should check to assure that loads resulting from the tie spacings do not exceed the working capacity of the rock anchors.

Bending and welding of high-tensile-strength steel tie rods should not be permitted without the approval of the tie manufacturer. Any approved welding should be by a welder certified by the American Welding Society (AWS) using approved written welding procedures.

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.

8.6—Underground structures

8.6.1 Discussion—Underground structures differ from corresponding surface installations in that the construction takes place inside an excavation instead of in the open, presenting unique problems in handling and supporting formwork and in the associated placement of concrete. 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](#).

8.6.2 Design loads

8.6.2.1 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/ft² (144 kPa) have been induced in areas of overbreak and near vertical bulkheads from concrete placed pneumatically or by positive displacement pump ([ACI SP-4](#)). Overbreak is the excess removal of rock or other excavated 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/ft² (72 kPa) acting normally to the form plus the dead weight of the concrete placed pneumatically or by pump ([ACI SP-4](#)).

8.6.2.2 Lateral loads—For shafts and exterior walls against rock, the values listed in [4.2.2](#) 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 in addition 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 [8.6.2.1](#).

8.6.3 Drawings—In addition to the provisions of [Chapters 3, 4, and 5](#), the following data should be included on the drawings for specialized formwork and formwork for tunnels:

a) All pressure diagrams used in the design of the form, including diagrams for uplift, unbalanced lateral or vertical loads, pressurized concrete, or any other load applicable to the particular installation

b) Recommended method of supplemental strutting or bracing to be employed in areas where form pressures can exceed those listed due to abnormal conditions

c) 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

d) Concrete placement method and, for tunnel arch forms, whether the design is based on the bulkhead system of concrete placement or the continuously advancing slope method

e) The capacity and working pressure of the pump and size, length, and maximum embedment of the discharge line when placement by pumping is anticipated

8.6.4 Construction—The two basic methods of placing concrete in 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 concrete placement operation, the recommended minimum stripping time is 12 hours for exposed surfaces and 8 hours 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 minutes

or less and should be established by laboratory tests, 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.

8.6.5 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 usually alleviates normal shrinkage and warping of wood form materials.

CHAPTER 9—SPECIAL METHODS OF CONSTRUCTION

9.1—Preplaced-aggregate concrete

9.1.1 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 percent (ACI 304.1R).

9.1.2 Design considerations—Due to the method of placement, the lateral pressures on formwork are considerably different from those developed for conventional concrete, as described in 4.2.2. The formwork engineer/contractor should be alerted to the unique problems that may occur in preplaced aggregate placements. In mass placements, heat of hydration and drying shrinkage are important considerations. Differential pressures may occur in the form structure when mortar injection varies greatly from one form face to another. For additional information, refer to 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. Provisions 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)

b) The lateral and uplift pressure of the injected mortar, as an equivalent fluid; the mortar normally weighs 130 lb/ft³ (21 kN/m³), but can weigh as much as 200 lb/ft³ (32 kN/m³) for high-density mortars

The time required for the initial set of the fluidized mortar 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 [m/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.

9.1.3 Construction—In addition to the information presented in Chapter 5, the forms should be mortar-tight and effectively vented because preplaced-aggregate concrete entails forcing mortar into the voids around the coarse aggregate.

9.1.4 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. Formwork should be designed for the effects of external vibration.

9.2—Slipforms

9.2.1 Discussion—Refer to ACI 313 for silo construction. Slipforming is a quasi-continuous 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.

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 follow 8.6. Slipforms used on mass concrete structures, such as dams, should follow 8.5.

9.2.2 Vertical slipforms

9.2.2.1 Slipforms can be used for vertical structures, such as silos, storage bins, building cores, bearing wall build-

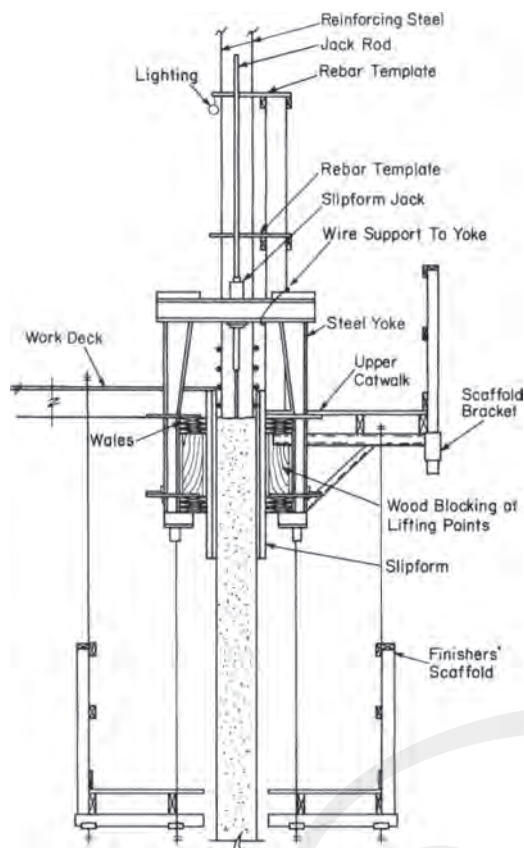


Fig. 9.2.2.1—Typical vertical slipform with deck and work platforms supported on wales.

ings, piers, chimneys, shaft linings, communication and observation towers, nuclear shield walls, and similar structures. Vertical slipforms, with concrete placed 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.

A vertical slipform system (refer to Fig. 9.2.2.1) has five main components: sheathing, wales, yokes, jacks, and jack-rods, 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:

- a) Support and hold the sheathing in place
- b) Transmit the lifting force from the yokes to the sheathing and to the other elements of the form
- c) 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 jack-rods 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.

9.2.2.2 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 retained by the contractor. The drawings should 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 are significant variations in equipment between manufacturers.

9.2.2.3 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, or concentrated buggy wheel loads, whichever is greater 75 lb/ft² (3.6 kPa)
 Beams, trusses, and wales 50 lb/ft² (2.4 kPa)
 Light-duty finishers' scaffolding 25 lb/ft² (1.2 kPa)

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

$$C_{CP} = c_1 + \frac{6000R}{T} \quad \text{(U.S. customary units)}$$

where $c_1 = 100 \text{ lb/ft}^2$

$$C_{CP} = c_1 + \frac{524R}{T + 17.8} \quad \text{(SI units)}$$

where $c_1 = 4.8 \text{ kPa}$.

The value of $c_1 = 100 \text{ lb/ft}^2$ (4.8 kPa) is justified because vibration is slight in slipform work; 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/ft² (7.2 kPa).

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

9.2.2.6 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 demands 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 estab-

lish 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 preferably be checked every 2 hours but at a minimum once during every 4 hours that the slide is in operation. 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.

9.2.3 Horizontal slipforms—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. 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 general provisions of 4.1.4 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.

9.3—Permanent forms

9.3.1 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.

9.3.2 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 (refer to Chapters 4 and 5). 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 is used as a permanent form and the deck will become an integral part of the structure, the deck's shape, depth, gauge, 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.

When composite metal deck requires shoring to minimize its deflection due to the concrete placement, the camber of the members supporting the completed composite slab and deck should be considered. If the supporting members are cambered for the dead load of the concrete, and that load is prevented from being applied to the supporting members due to the presence of the shoring, there may be excess camber left in the supporting members. The engineer/architect who designed the structure should consider this effect and adjust the camber appropriately.

9.3.3 Installation

9.3.3.1 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, as applicable to the project. 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.

9.3.3.2 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 on supporting members for lateral stiffness) should be tightly joined 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 entrapment of water.

9.3.4 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.

9.4—Forms for prestressed concrete construction

9.4.1 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. Pretensioning or post-tensioning of strands, cables, or rods can be done with or without side forms of the member in place, as discussed in 9.4.2. 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 concrete placement sequence for certain structures should also be planned so that concrete is not subjected to bending stress caused by deflection of the formwork.

9.4.2 Design

9.4.2.1 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.

9.4.2.2 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 forming components should be planned for removal 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.

9.4.2.3 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.

9.4.3 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.

9.4.4 Tolerances—Prescribed ranges of tolerances for job-site precast and plant-manufactured precast-prestressed concrete members are given in **ACI 117** and **PCI MNL 135-00**.

9.4.5 Curing—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.

9.4.6 Worker safety—Safety shields should be provided at end anchorages of prestressing beds or where necessary for the protection of workers or equipment against possible breakage of prestressing strands, cables, or other assemblies during prestressing or casting operations.

9.5—Forms for site precasting

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

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

9.5.3 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.

9.5.4 Tolerances—Prescribed tolerances for precast-concrete construction are listed in [ACI 117](#).

9.5.5 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.

9.6—Use of precast concrete for forms

9.6.1 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. Match casting is a process where a previously cast element is used as the bulkhead for the casting of a subsequent element to assure tight fit. Match casting is often used in the process of casting units for segmental bridge construction.

9.6.2 Design

9.6.2.1 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.

9.6.2.2 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.

9.6.2.3 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 Items 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.

9.6.2.4 Code requirements—Precast concrete forms used in composite design with cast-in-place concrete in buildings should be designed in accordance with [ACI 318](#).

9.6.3 During and after concrete placement

9.6.3.1 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.

9.6.3.2 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 concrete placement, protection of precast architectural concrete form facings may need to be considered.

9.7—Forms for concrete placed under water

9.7.1 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 where concrete is to be placed. 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 [9.1](#). The grout is introduced at the bottom and the water is displaced upward as the grout rises.

9.7.2 Underwater bucket and tremie

9.7.2.1 Design—Forms for underwater concrete placement are designed with the same considerations as other forms covered in [4.2](#), 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. Ignoring the effects of submergence will result in a practical conservative 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.

9.7.2.2 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.

Multi-use 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.

9.7.3 Preplaced aggregate

9.7.3.1 Design—The formwork should be designed with the same considerations as mentioned previously in 9.1.2.

9.7.3.2 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 10—REFERENCES

Committee documents are listed first by document number and year of publication followed by authored documents listed alphabetically.

American Concrete Institute

ACI 117-10—Specification for Tolerances for Concrete Construction and Materials and Commentary

ACI 207.1R-05—Guide to Mass Concrete (Reapproved 2012)

ACI 224R-01—Control of Cracking in Concrete Structures (Reapproved 2008)

ACI 228.1R-03—In-Place Methods to Estimate Concrete Strength

ACI 237R-07—Self-Consolidating Concrete

ACI 301-10—Specifications for Structural Concrete

ACI 303R-12—Guide to Cast-in-Place Architectural Concrete Practice

ACI 304.1R-92—Guide for Use of Preplaced-Aggregate Concrete for Structural and Mass Concrete Applications

ACI 304.2R-96—Placing Concrete by Pumping Methods (Reapproved 2008)

ACI 305R-10—Guide to Hot Weather Concreting

ACI 306R-10—Guide to Cold Weather Concreting

ACI 309.2R-98—Identification and Control of Visible Effects of Consolidation on Formed Concrete Surfaces (Reapproved 2005)

ACI 311.4R-05—Guide for Concrete Inspection

ACI 313-97—Standard Practice for Design and Construction of Concrete Silos and Stacking Tubes for Storing Granular Materials

ACI 318-11—Building Code Requirements for Structural Concrete and Commentary

ACI 332.1R-06—Guide to Residential Concrete Construction

ACI 334.1R-92—Concrete Shell Structures Practice and Commentary (Reapproved 2002)

ACI 372R-03—Design and Construction of Circular Wire and Strand Wrapped Prestressed Concrete Structures

ACI 373R-97—Design and Construction of Circular Prestressed Concrete Structures with Circumferential Tendons

ACI 347.2R-05—Guide for Shoring/Reshoring of Concrete Multistory Buildings

ACI 347.3R-13—Guide for Formed Concrete Surfaces

ACI SP-2(07)—Manual of Concrete Inspection

ACI SP-4—Formwork for Concrete, seventh edition

ACI SP-34—Concrete for Nuclear Reactors

American Institute of Steel Construction

AISC 325-11—Steel Construction Manual

American Iron and Steel Institute

AISI D100-08—Cold-Formed Steel Design Manual

American National Standards Institute

ANSI A48.1-1986—Forms for One-Way Concrete Joist Construction

ANSI A48.2-1986—Forms for Two-Way Concrete Joist Construction

ANSI A208.1-2009—Particleboard

American Society of Civil Engineers

ASCE/SEI 7-10—Minimum Design Loads for Buildings and Other Structures

ASCE/SEI 37-02—Design Loads on Structures during Construction

American Wood Council

ANSI/AWC NDS-2012—National Design Specification for Wood Construction

APA—The Engineered Wood Association

APA D510-2012—Panel Design Specification

APA V345-2012—Design/Construction Guide: Concrete Forming

APA Y510-1998—Plywood Design Specification

ASTM International

ASTM A446-76(1981)—Standard Specification for Steel Sheet, Zinc-Coated (Galvanized) by the Hot-Dip Process, Structural (Physical) Quality

ASTM C1611/C1611M-09—Standard Test Method for Slump Flow of Self-Consolidating Concrete

Canadian Standards Association

CSA-O86M-84—Engineering Design in Wood

Deutsches Institut für Normung

DIN 18218:2010-01—Frischbetondruck auf Lotrechte Schalungen (Pressure of Fresh Concrete on Vertical Formwork)

Precast/Prestressed Concrete Institute

MNL 135-00—Tolerance Manual for Precast and Prestressed Concrete Construction

Scaffolding, Shoring, and Forming Institute

SH 301-03—Horizontal Shoring Beam Safety Rules

SH 304-00—Recommended Frame Shoring Erection Procedure

U.S. Department of Commerce, National Institute of Standards and Technology

PS1-09—Construction and Industrial Plywood

PS20-10—Performance Standard for Wood-Based Structural-Use Panels

U.S. Department of Labor, Occupational Safety and Health Administration

OSHA 1926-07—Safety and Health Regulations for Construction

Authored references

ACI Committee 622, 1957, “Form Construction Practices,” *ACI Journal Proceedings*, V. 53, No. 12, June, pp. 1105-1118.

ACI Committee 622, 1958, “Pressures on Formwork,” *ACI Journal Proceedings*, V. 55, No. 2, Aug., pp. 173-190.

Agarwal, R. K., and Gardner, N. J., 1974, “Form and Shore Requirements for Multistory Flat Slab Type Buildings,” *ACI Journal Proceedings*, V. 71, No. 11, Nov., pp. 559-569.

American Institute of Timber Construction, 2012, *Timber Construction Manual*, sixth edition, John Wiley & Sons, New York, 648 pp.

American Wood Council, 2012, *Wood Frame Construction Manual*, Leesburg, VA.

Barnes, J. M., and Johnston, D. W., 1999, “Modification Factors for Improved Prediction of Fresh Concrete Lateral Pressures on Formwork,” Institute of Construction, Department of Civil Engineering, North Carolina State University, Raleigh, NC, Oct., 90 pp.

Barnes, J. M., and Johnston, D. W., 2003, “Fresh Concrete Lateral Pressure on Formwork,” *Proceedings of the ASCE-CI Construction Research Congress*, 8 pp.

British Cement Association, 1992, “Hi-Rib Permanent Formwork Trials,” Report and Appendix RE1.031.01.1 BCA, Slough, UK, Feb., 22 pp., and July, 9 pp.

Bryer, D.; Fridley Jr., K.; and Pollock, K. C., 2006, *Design of Wood Structures*, sixth edition, McGraw-Hill, 1025 pp.

Clear, C. A., and Harrison, T. A., 1985, “Concrete Pressure on Formwork,” *CIRIA Report No. 108*, Construction Industry Research and Information Association, London, UK, 32 pp.

CRSI, 2009, *Manual of Standard Practice*, 28th edition, Concrete Reinforcing Steel Institute, Schaumburg, IL, 144 pp.

“DIN Standard on Formwork Pressures Updated,” 2010, *Concrete International*, V. 32, No. 6, June, pp. 27-29.

Dunston, P. S.; Johnston, D. W.; and McCain, P. P., 1994, “Formwork Pressures in Tall Walls with Extended Set Concrete,” *Concrete International*, V. 16, No. 11, Nov., pp. 26-34.

Gardner, N. J., 1980, “Pressure of Concrete against Formwork,” *ACI Journal Proceedings*, V. 77, No. 4, July-Aug., pp. 279-286.

Gardner, N. J., 1981, “discussion on ‘Pressure of Concrete Against Formwork,’” *ACI Journal Proceedings*, V. 78, No. 3, May-June, pp. 243-246.

Gardner, N. J., 1985, “Pressure of Concrete on Formwork—A Review,” *ACI Journal Proceedings*, V. 82, No. 5, July-Aug., pp. 744-753.

Gardner, N. J., and Ho, P. T.-J., 1979, “Lateral Pressure of Fresh Concrete,” *ACI Journal Proceedings*, V. 76, No. 7, July, pp. 809-820.

Gardner, N. J.; Keller, L.; Quattrociocchi, R.; and Charitou, G., 2012, “Field Investigation of Formwork Pressures using Self Consolidating Concrete,” *Concrete International*, V. 34, No. 1, Jan., pp. 41-47.

Grundy, P., and Kabaila, A., 1963, “Construction Loads on Slabs with Shored Formwork in Multistory Buildings,” *ACI Journal Proceedings*, V. 60, No. 12, Dec., pp. 1729-1738.

Hurd, M. K., 1993, “Nonmetallic Form Ties,” *Concrete Construction*, V. 38, No. 10, pp. 695-699.

Hurd, M. K., 1994, “Plastic Form Liners,” *Concrete Construction*, V. 39, No. 11, Nov., pp. 847-853.

Hurd, M. K., 1996, “Choosing and Using a Form Release Agent,” *Concrete Construction*, V. 41, No. 10, pp. 732-736.

Hurd, M. K., 1997a, “Using Glass-Fiber-Reinforced-Plastic Forms,” *Concrete Construction*, V. 42, No. 9, pp. 689-692.

Hurd, M. K., 1997b, “Expand Your Forming Options,” *Concrete Construction*, V. 42, No. 9, Sept., pp. 725-728.

Johnston, D. W., 2010, “Field Measurement of Concrete Lateral Pressure in Formwork,” *Proceedings of the ASCE-CI Construction Research Congress*, pp. 1335-1344.

Johnston, D. W.; Kahn, K. P.; and Phillips, J. B., 1989, “Formwork Pressures in Tall and Thick Concrete Walls,” *Journal of Construction Engineering and Management*, V. 115, No. 3, Sept., pp. 444-461. doi: 10.1061/(ASCE)0733-9364(1989)115:3(444)

Khayat, K. H., and Omran, A. F., 2011, “Field Verification of Formwork Pressure Prediction Models,” *Concrete International*, V. 33, No. 6, June, pp. 33-39.

Lange, D. A.; Birch, B.; Henschen, J.; Liu, Y.-S.; Tejeda-Dominquez, F.; and Struble, L. J., 2008, “Modeling Formwork Pressure of SCC,” *Proceedings of the 3rd North American Conference on Design and Use of Self Consolidating Concrete (SCC2008)*, 6 pp.

Noble, J., 1975, "Stop Guessing at Reshore Loads—Measure Them," *Concrete Construction*, V. 20, No. 7, pp. 277-280.

Proske, T., and Graubner, C.-A., 2008, "Formwork Pressure Using Self-Compacting Concrete," Technische Universität Darmstadt, Institut für Massivbau, 25 pp.

Randall Jr., F. A., and Courtois, P. D., 1976, "Side Form Spacers," *ACI Journal Proceedings*, V. 73, No. 2, Feb., pp. 116-120.

Smulski, S., ed., 1997, *Engineered Wood Products: A Guide for Specifiers, Designers, and Users*, PFS Research Foundation, Madison, WI, 330 pp.

Steel Joist Institute, 2010, "Standard Specifications and Load and Weight Tables for Steel Joists and Joist Girders," 43rd edition, Florence, SC, 77 pp.

Stivaros, P. C., and Halvorsen, G. T., 1990, "Shoring/Reshoring Operations for Multistory Buildings," *ACI Structural Journal*, V. 87, No. 5, Sept.-Oct., pp. 589-596.

The Aluminum Association, 2010, *Aluminum Design Manual*, Arlington, VA.

U.S. Department of Agriculture, 2010, *Wood Handbook: Wood as an Engineering Material*, General Technical Report FPL-GTR-190, Forest Products Laboratory, Madison, WI, 508 pp. www.fpl.fs.fed.us/documnts/fplgtr/fpl_gtr190.pdf

Ziverts, G. J., 1964, "A Study of Cardboard Voids for Prestressed Concrete Box Slabs," *PCI Journal*, V. 9, No. 3, pp. 66-93, and V. 9, No. 4, pp. 33-68.





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