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ACI 347R-14

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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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.

preshores—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.

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 minimized. 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.

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 jursidictions 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 preplacement 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 multistory 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

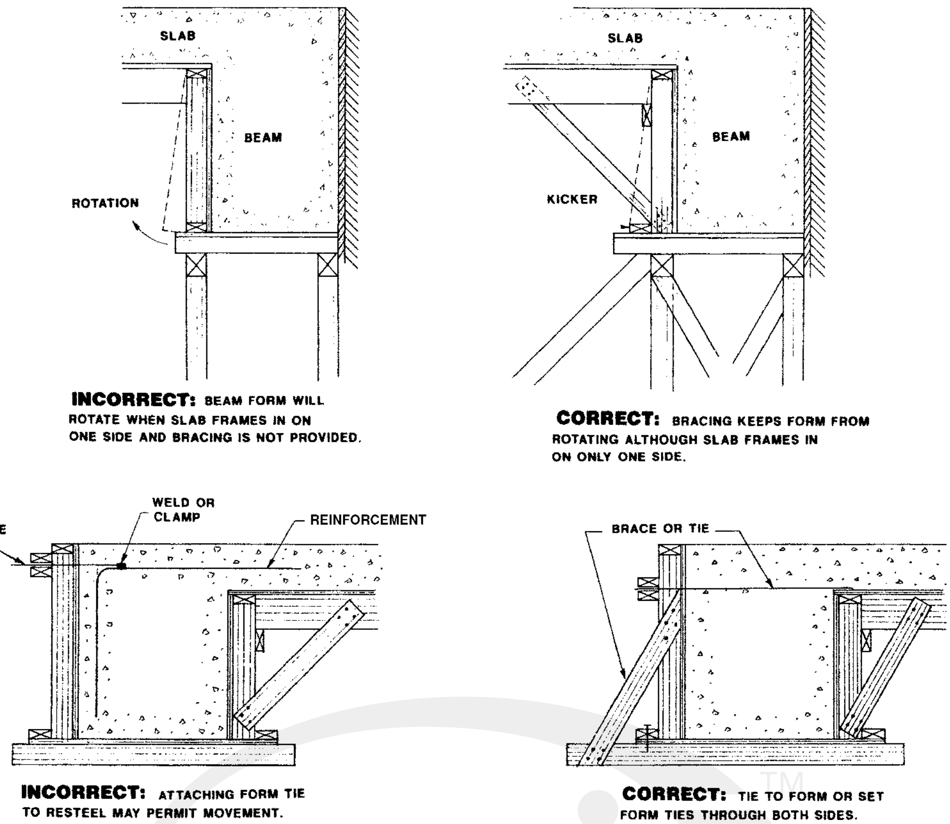

Fig. 4.1.4—Prevention of rotation is important where slab frames into beam form on only one side.

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/ft^2 (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/ft^2 (3.6 kPa).

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

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/ft^2), can be determined in accordance with the appropriate equation listed in Table 4.2.2.1a(a).

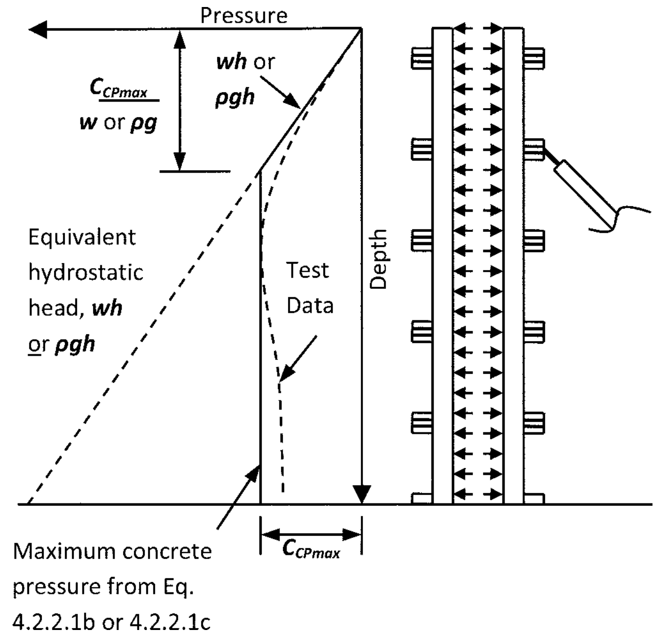

Fig. 4.2.2—Concrete lateral pressure distribution.

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

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

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

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

with a minimum of $600C_w$ lb/ft^2, 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.

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

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

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

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

with a minimum of $30C_w$ kPa, but in no case greater than ρ*gh,* 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 - Inch-pound version

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 than15 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
$w > 150$	$w/145$ lb/ft^3	$\rho > 2400$	$w/2320$ kg/m^3

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

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/ft^2 (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.