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(Reapproved 1999)

Guide to Formwork for Concrete

Reported by ACI Committee 347

aci international®

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Errata
347R-94

This section of conversions was inadvertently omitted from the end of the Appendix of the Committee Document

Conversions of nonhomogeneous equations

Section 2.2.2—Lateral pressure of concrete (metric equivalents)

$$p_M = 0.24 h_{SI} \qquad (2\text{-}1)$$

a. For columns

$$p_M = 0.073 + \frac{8.0 R_{SI}}{T_C + 17.8} \qquad (2\text{-}2)$$

(maximum of 1.47 kgf/cm^2 or $0.24 h_{SI}$, whichever is least)

b. For walls, rate of placement not exceeding 2 m/hr

$$p_M = 0.073 + \frac{8.0 R_{SI}}{T_C + 17.8} \qquad (2\text{-}2a)$$

(maximum of 0.98 kgf/cm^2 or $0.24 h_{SI}$, whichever is least)

c. For walls, rate of placement 2 to 3 m/hr

$$p_M = 0.073 + \frac{11.78}{T_C + 17.8} + \frac{2.49 R_{SI}}{T_C + 17.8} \qquad (2\text{-}3)$$

(maximum 0.98 kgf/cm^2 or $0.24 h_{SI}$, whichever is least)

where

p_M = lateral pressure, kgf/cm2

R_{SI} = rate of placement, m/hr

T_C = temperature of concrete in the forms, deg C

h_{SI} = height of fresh concrete above point considered, m

Section 2.2.2—Lateral pressure of concrete (SI equivalant)

$$p_{SI} = 23.5 h_{SI} \qquad (2\text{-}1)$$

For columns

$$p_{SI} = 7.2 + \frac{785 R_{SI}}{T_C + 17.8} \qquad (2\text{-}2)$$

(maximum of 144 kPa for $23.5 h_{SI}$, whichever is least)

For walls, rate of placement not exceeding 2 m/hr

$$p_{SI} = 7.2 + \frac{785 R_{SI}}{T_C + 17.8} \qquad (2\text{-}2a)$$

(maximum of 95.8 kPa or $23.5 h_{SI}$, whichever is least)

For walls, rate of placement from 2 to 3 m/hr

$$p_{SI} = 7.2 + \frac{1156}{T_C + 17.8} + \frac{244 R_{SI}}{T_C + 17.8} \qquad (2\text{-}3)$$

(maximum of 95.8 kPa or $23.5 h_{SI}$, whichever is least)

where

P_{SI} = lateral pressure, kPa

R_{SI} = rate of placement, m/hr

T_C = temperature of concrete in the forms, deg C

h_{SI} = height of fresh concrete above point considered, m

Section 7.3.2.4—Lateral pressure of concrete (metric equivalent)

The lateral pressure of fresh concrete to be used in designing forms, ties, bracing, and wales may be calculated as follows:

$$p_M = c_1 + \frac{5.35 R_{SI}}{T_C + 17.8}$$

where

c_l = 0.05

p_M = lateral pressure, kgf/cm^2

R_{SI} = rate of placement, m/hr

T_C = temperature of concrete in the forms, deg C

Section 7.3.2.4—Lateral pressure of concrete (SI eqivalent)

The lateral pressure of fresh concrete to be used in designing forms, ties, bracing, and wales may be calculated as follows:

$$p_{SI} = c_1 + \frac{524 R_{SI}}{T_C + 17.8}$$

where

c_l = 4.79

P_{SI} = lateral pressure, kPa

R_{SI} = rate of placement, m/hr

T_C = temperature of concrete in the forms, degC

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Guide to Formwork for Concrete

Most ACI Standards and committee reports are gathered together in the annually revised ACI Manual of Concrete Practice. The several volumes are arranged to group related material together and may be purchased individually or in sets.The ACI Manual of Concrete Practice is also available on CD-ROM.

ACI Committees prepare standards and reports in the general areas of materials and properties of concrete, construction practices and inspection, pavements and slabs, structural design and analysis, structural specifications, and special products and processes.

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The final quality of a concrete structure depends on qualified people to construct it. ACI certification programs identify craftsmen, technicians, and inspectors who have demonstrated their qualifications. The following programs are administered by ACI to fulfill the growing demand in the industry for certified workers:

Concrete Flatwork Finisher

Concrete Flatwork Technician

Concrete Field Testing Technician—Grade I

Concrete Strength Testing Technician

Concrete Laboratory Testing Technician—Grade I

Concrete Laboratory Testing Technician—Grade II

Concrete Construction Inspector-In-Training

Concrete Construction Inspector

Concrete Transportation Construction Inspector-In-Training

Concrete Transportation Construction Inspector

This document may already contain reference to these ACI certification programs, which can be incorporated into project specifications or quality control procedures. If not, suggested guide specifications are available on request from the ACI Certification Department.

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1. Title and number of the document containing the problem and specific section in the document;
2. Concise description of the problem;
3. If possible, suggested revisions for mitigating the problem.

The Institute's Engineering Staff will review and take appropriate action on all comments and suggestions received. Members as well as nonmembers of the Institute are encouraged to assist in enhancing the accuracy and usefulness of ACI documents.

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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 report advises the contractor on the best ways to meet the specification requirements safely and economically. Separate chapters deal with design, construction, and materials for formwork. Considerations peculiar to architectural concrete are also outlined in a separate chapter. Other sections are devoted to formwork for bridges, shells, mass concrete, and underground work. The concluding chapter on formwork for special methods of construction includes slipforming, preplaced aggregate concrete, tremie concrete, precast, and prestressed concrete.

Keywords: aggregates; aluminum; anchors (fasteners); architectural concrete; bridges (structures); canal linings; coatings; composite materials; concrete construction; construction costs; construction materials; culverts; falsework; fasteners; fiberboard; folded plates; form removal; formwork (construction); foundations; glass fibers; hangers; inserts; insulating boards; loads (forces); long span; lumber; mass concrete; multistory buildings; parting agents; plastic forms; plywood; precast concrete; preplaced aggregate concrete; pressure; prestressed concrete; quality control; reinforced concrete; roofs; safety; safety factor; settlement (structural); shells (structural forms); shelters; shoring; slipform construction; specifications; structural design; structural steels; subsurface structures; tolerances (mechanics); tunnels; underwater construction.

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ACI 347R-94 became effective March 1, 1994 and supersedes ACI 347R-88.

PREFACE

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

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

The first standard (ACI 347-63) was adopted at the 1962 ACI fall meeting and ratified by letter ballot in 1963. Subsequent revisions were ACI 347-68 and ACI 347-78. For the 1988 revision the standard was presented as a committee report because of changes in the ACI policy on style and format of standards. This guide is a revision of ACI 347R-88.

A major contribution of the committee has been the sponsorship and review of *Formwork for Concrete*[1.3] by M.K. Hurd, first published in 1963 and now in its fifth edition. This is the most comprehensive and widely used work on this subject ever published (the Japan National Council on Concrete has published a Japanese translation).

* Those references cited in the Preface will be found in the Reference section of Chapter 1.

CHAPTER 1—INTRODUCTION

1.1—Scope

This guide covers:

a) Information to be included on contract plans and in contract specifications.
b) Design criteria for horizontal and vertical forces on formwork.
c) Design considerations, including safety factors to be used in 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.

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

1.2—Definitions

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

Backshores—Shores placed snugly under a concrete slab or structural member after the original formwork and shores have been removed from a small area without allowing the slab or member to deflect or support its own weight or existing construction loads from above.

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

Diagonal bracing—Supplementary formwork members designed to resist lateral loads.

Engineer/architect—The architect, engineer, the architectural firm, the engineering firm, or other agency issuing project drawings and specifications and/or administering the work under project specifications and drawings.

Flying forms—Large mechanically handled sections of formwork; frequently include supporting truss, beam, or scaffolding units completely unitized. Term usually applies to floor forming systems.

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

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

Ganged forms—Prefabricated panels joined to make a larger unit for convenience in erecting, stripping, and reusing.

Horizontal lacing—Horizontal members attached to shores to reduce their unsupported length, thereby increasing load capacity.

Multi-tier shoring—Single post shores used in two or more tiers to increase the height of the shoring system.

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

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

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

1.3—Achieving economy in formwork

The engineer/architect can help overall economy in the structure by planning so that formwork costs are minimized. The cost of formwork in the U.S. may be as much as 60 percent of the total cost of the concrete in place. This investment demands careful thought and planning by the engineer/architect when designing and specifying the structure, and by the contractor when designing and constructing the formwork.

The contractor, by preparing formwork working drawings, can foresee problems on paper and can make necessary corrections. The working drawings should give project site employees a clear picture of what is required and how to achieve it.

Following are examples of how the engineer/architect can plan the structure so that formwork economy may best be achieved:

a) To simplify formwork and permit maximum reuse, 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 cutouts, 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 beams as well as beams framing into columns), the supporting structures for the beam forms can be carried on a level platform supported on shores.

d) When the widths and depths are made the same for beams and joists, and the available sizes of dressed lumber, plywood, and the various ready-made formwork components are considered when determining the sizes of structural members, labor time will be saved in cutting, measuring, and leveling.

e) Where commercially available forming systems such as one-way or two-way joist systems are used, design should be based on the use of one standard depth wherever possible.

f) The structural design should be prepared simultaneously with the architectural design so that dimensions can be better coordinated. Room sizes can often be varied a few inches to accommodate the structural design.

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 drawings. 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.

1.4—Contract documents

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

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

1.4.1 *Individual specifications* — The specification writer is encouraged to refer to this guide as a source of recommendations that can be written into the proper language for contract documents.

For any concrete structure, the specification for formwork will have much to do with the overall economy and quality of the finished work. Such a specification must be tailored for each particular job, must indicate exactly what will be expected of the contractor, and should be so written as to result in economy and safety.

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

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

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

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

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

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

1.4.4 *Design, inspection, review, and approval of formwork* — Although the safety of formwork is the responsibility of the contractor, the engineer, architect, or approving agency may under certain circumstances wish to review and/or 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, for structures whose designs were based on a particular method of construction, for structures in which the forms impart a desired architectural finish, for certain post-tensioned structures, for folded plates, for thin shells, or for long-span roof structures. The following items should be clarified in the contract documents:

a) By whom formwork will be designed

b) By whom, when, and for what features formwork will be inspected

c) What reviews and/or approvals will be required:

1. for formwork drawings
2. for the forms before concreting and during concreting
3. who will give such reviews and/or approvals

1.4.5 *Contract drawings* — The contract drawings should include all information necessary to the contractor for formwork design and for the preparation of formwork drawings, 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.

c) The live load and superimposed dead load for which the structure is designed and any live load reduction used. This is a requirement of the *ACI Building Code* (ACI 318).

d) Intermediate supports under stay-in-place forms, such as metal deck used for forms and permanent forms of other materials; supports and/or bracing required by the structural engineer's design for composite action; and any other special supports.

e) The location and order of erection and removal of shores for composite construction.

f) 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, must be given in sufficient detail to permit the contractor to build the forms. Camber should be stipulated for measurement after initial set and before decentering.

g) Special requirements for post-tensioned concrete members. The effect of load transfer during tensioning of post-tensioned members may be critical, and the contractor should be advised of any special provisions that must be made in the formwork for this condition.

h) Amount of desired camber for slabs or other structural members to compensate for deflection of the structure. Measurements of camber attained should be made at soffit level after initial set and before removal of formwork supports.

i) Where chamfers are required or prohibited on beam soffits or column corners.

j) 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.

k) Where architectural features, embedded items, or the work of other trades could change the location of structural members such as joists in one-way or two-way joist systems, such changes or conditions should be coordinated by the engineer/architect.

l) 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 drawings since they may play a key role in the structural design of the form.

1.5—References

1.1. ACI Committee 622, "Form Construction Practices," ACI JOURNAL, *Proceedings* V. 53, No. 12, June 1957, pp. 1105-1118.

1.2. ACI Committee 622, "Pressures on Formwork," ACI JOURNAL, *Proceedings* V. 55, No. 2, Aug. 1958, pp. 173-190.

1.3 Hurd, M.K., *Formwork for Concrete*, SP-4, American Concrete Institute, Detroit, 5th Edition, Revised 1989, 486 pp.

CHAPTER 2—DESIGN

2.1—General

2.1.1 *Planning* — Any form, regardless of size, should be planned in every particular prior to its construction. The amount of planning required will depend on the size, complexity, and importance (considering reuses) of the form. A design analysis should be made for all formwork. Stability and buckling should be investigated in all cases.

2.1.2 *Design methods* — Formwork is made of many different materials, and the commonly used design practices for each material are followed (see Chapter 4). For example, wood forms are designed by working-stress methods recommended by the National Forest Products Association. When the concrete structure becomes a part of the formwork support system, as in many multistory buildings, it is important for the form designer to recognize that the concrete usually has been designed by the strength method.

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

2.1.3 *Basic objectives* — Formwork should be designed so that concrete slabs, walls, and other members will be of correct dimensions, shape, alignment, elevation, and position and 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 must 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 engineer hired by the contractor to design and be responsible for the formwork.

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

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

b) Inadequate reshoring.

c) Overstressed reshoring.

d) Inadequate provisions to prevent rotation of beam forms where the slabs frame into them on only one side (see Fig. 3.5.1.b).

e) Inadequate anchorage against uplift due to battered form faces.

f) Insufficient allowance for eccentric loading due to placement sequences.

g) Failure to investigate bearing stresses in members in contact with shores or struts.

h) Failure to provide proper lateral bracing or lacing of shoring.

i) Failure to investigate the slenderness ratio of compression members.

j) Inadequate provisions to tie corners of intersecting cantilevered forms together.

k) Failure to account for loads imposed on anchorages during gap closure in aligning formwork.

2.1.5 *Formwork drawings and calculations* — Before constructing forms, the contractor, if required, will submit detailed drawings and/or design calculations of proposed formwork for review and/or approval by the engineer/architect or approving agency. If such drawings are not in conformity with contract documents as determined by the engineer/architect or approving agency, the contractor will make such changes as may be required prior to start of construction of the formwork.

The review approval of the formwork drawings in no way relieves the contractor of the responsibility for adequately constructing and maintaining the forms so that they will function properly. If reviewed by persons other than those employed by the contractor, the review or approval indicates no exception is taken by the reviewer to: the assumed design loadings in combination

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

with design stresses shown; proposed construction methods; placement rates, equipment, and sequences; the proposed form materials; and the overall scheme of formwork.

All major design values and loading conditions should be shown on formwork drawings. These include assumed values of live load; the compressive strength of concrete for formwork removal and for application of construction loads; rate of placement, temperature, height and drop of concrete; weight of moving equipment which may be operated on formwork; foundation pressure; design stresses; camber diagrams; and other pertinent information, if applicable.

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

a) Procedures, sequence, and criteria for removal of forms, shores, and reshores.

b) Design allowance for construction loads on new slabs should be shown when such allowance will affect the development of shoring and/or reshoring schemes (see Sections 2.5.3 and 3.8 for shoring and reshoring of multistory structures).

c) Anchors, form ties, shores, lateral bracing, and horizontal lacing.

d) Field adjustment of forms.

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 may damage concrete.

k) Removal of spreaders or temporary blocking.

l) Cleanout holes and inspection openings.

m) Construction joints, contraction joints, and expansion joints to conform to design drawings (ACI 318).

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) Camber.

q) Mudsills or other foundation provisions for formwork.

r) Special provisions such as safety, fire, drainage, and protection from ice and debris at water crossings.

s) Formwork coatings.

t) Notes to formwork erector showing size and location of conduits and pipes embedded in concrete according to ACI 318 (Section 6.3).

u) Temporary openings or attachments for climbing crane or other material handling equipment.

2.2—Loads

2.2.1 *Vertical loads* — Vertical loads consist of dead load and live load. The weight of formwork plus the weight of freshly placed concrete is dead load. The live load includes the weight of workmen, equipment, material storage, runways, and impact.

Vertical loads assumed for shoring and reshoring design for multistory construction must include all loads transmitted from the floors above as dictated by the proposed construction schedule. Refer to Section 2.5, Shores.

Vertical supports and horizontal framing should be designed for a minimum live load of 50 psf of horizontal projection. When motorized carts are used the minimum live load should be 75 psf.

The minimum design load for combined dead and live loads should be 100 psf, or 125 psf if motorized carts are used.

2.2.2 *Lateral pressure of concrete* — Unless the conditions of Section 2.2.2.1 or 2.2.2.2 are met, formwork should be designed for the lateral pressure of the newly placed concrete given in Eq. (2-1). Maximum and minimum values given for other pressure formulas do not apply to Eq. (2-1) (see Appendix for metric conversions of equations in this section).

$$p = wh \qquad \text{(Eq. 2-1)}$$

where:

p = lateral pressure, psf
w = unit weight of fresh concrete, pcf
h = depth of fluid or plastic concrete, ft

For columns or other forms that may be filled rapidly before any stiffening of the concrete takes place, h should be taken as the full height of the form, or the distance between construction joints when more than one placement of concrete is to be made.

2.2.2.1 For concrete made with Type I cement,* weighing 150 pcf, containing no pozzolans or admixtures, having a slump of 4 in. or less and normal internal vibration to a depth of 4 ft or less, formwork may be designed for a lateral pressure as follows, where R = rate of placement, ft per hr; and T = temperature of concrete in the form, deg F.

FOR COLUMNS

$$p = 150 + 9000\,R/T \qquad \text{(Eq. 2-2)}$$

with a maximum of 3000 psf, a minimum of 600 psf, but in no case greater than 150 h.

FOR WALLS with rate of placement less than 7 ft per hr

$$p = 150 + 9000\,R/T \qquad \text{(Eq. 2-2a)}$$

with a maximum of 2000 psf, a minimum of 600 psf, but in no case greater than 150h.

* The committee has insufficient test data with other cement types. See original statement of formulas in Reference 1.2.

FOR WALLS with a rate of placement of 7 to 10 ft per hr

$$p = 150 + 43{,}400/T + 2800\, R/T \quad \text{(Eq. 2-3)}$$

with a maximum of 2000 psf, a minimum of 600 psf, but in no case greater than 150 h.

2.2.2.2 Alternatively, a method based on appropriate experimental data may be used to determine the lateral pressure used for form design (References 2.1 through 2.5).

2.2.2.3 If concrete is pumped from the base of the form, the form should be designed for full hydrostatic head of concrete wh plus a minimum allowance of 25 percent for pump surge pressure. In certain instances pressures may be as high as the face pressure of the pump piston.

2.2.2.4 Caution must be taken when using external vibration or concrete made with shrinkage compensating or expansive cements. Pressures in excess of equivalent hydrostatic may occur.

2.2.2.5 For slipform lateral pressures, see Section 7.3.2.4.

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

2.2.3.1 For building construction, in no case should the assumed value of horizontal load due to wind, dumping of concrete, inclined placement of concrete, and equipment acting in any direction at each floor line be less than 100 lb per linear ft of floor edge or 2 percent of total dead load on the form distributed as a uniform load per linear foot of slab edge, whichever is greater.

2.2.3.2 Wall form bracing should be designed to meet the minimum wind load requirements of ANSI A58.1 or of the local building code, whichever is more stringent. For wall forms exposed to the elements, the minimum wind design load should not be less than 15 psf. Bracing for wall forms should be designed for a horizontal load of at least 100 lb per linear ft of wall, applied at the top.

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

2.2.4 *Special loads* — The formwork should be designed for any special conditions of construction likely to occur, such as unsymmetrical placement of concrete, impact of machine-delivered concrete, uplift, concentrated loads of reinforcement, form handling loads, and storage of construction materials. Form designers should be alert to provide for special loading conditions, such as walls constructed over spans of slabs or beams which 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 or architect. See Section 3.8 for special conditions pertaining to multistory work.

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

2.3—Unit stresses

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

2.4—Safety factors for accessories

Table 2.4 shows recommended minimum factors of safety for formwork accessories such as form ties, form anchors, and form hangers. In selecting these accessories, the formwork designer should be certain that materials, furnished for the job meet these minimum ultimate strength safety requirements.

Table 2.4—Minimum safety factors of formwork accessories*

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

* Safety factors are based on ultimate strength of accessory.

2.5—Shores

2.5.1 *General* — Shores are defined as vertical or inclined support members designed to carry the weight of formwork, concrete, and construction loads above.

2.5.2 *Splices* — Field-constructed butt or lap splices of timber shoring are not recommended unless they are made using fabricated hardware devices of demonstrated strength and stability. If plywood or lumber splices are made for timber shoring, they should be designed against buckling and bending as for any other structural compression member.

2.5.3 *Multistory structures* — Prior to 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.

Shores and reshores or backshores (as defined in Section 3.8) must be designed to carry all loads transmitted to them. A rational analysis should be used to determine the number of floors to be shored, reshored, or backshored and to determine the loads transmitted to the floors, shores, and reshores or backshores as a result of the construction sequence.

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

1. Structural design load of the slab or member including live load, partition loads, and other loads for which the engineer 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 drawings and be taken into consideration when performing this analysis.
2. Dead load weight of the concrete and formwork.
3. Construction live loads, such as placing crews and equipment or stored materials.
4. Design strength of concrete specified.
5. Cycle time between placement of successive floors.
6. Strength of concrete at time it is required to support shoring loads from above.
7. 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.[2.6,2.7]
8. Span of slab or structural member between permanent supports.
9. Type of formwork systems, i.e., span of horizontal formwork components, individual shore loads, etc.
10. Minimum age where appropriate.

Commercially available test cells can be placed under selected shores to monitor actual shore loads to guide the shoring and reshoring process as construction proceeds.[2.8]

2.6—Bracing and lacing

The formwork system should be designed to transfer all horizontal loads to the ground or to completed construction in such a manner as to insure 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 may be considered in design to hold in place and increase the buckling strength of individual shores and reshores or backshores. Lacing should be provided in whatever directions are necessary to produce the correct slenderness ratio l/r for the load supported, where l = unsupported length and r = least radius of gyration. The braced system should be anchored in a manner to insure stability of the total system.

2.7—Foundations for formwork

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

2.8—Settlement

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

2.9—References

2.1. Gardner, N.J., "Pressure of Concrete Against Formwork," ACI JOURNAL, *Proceedings* V. 77, No. 4, July-Aug. 1980, pp. 279-286, and Discussion, *Proceedings* V. 78, No. 3, May-June 1981, pp. 243-246.

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

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

2.4. "Pressure of Concrete on Vertical Formwork (Frischbeton auf Lotrechte Schalungen)," (DIN 18218), Deutsches Institut für Normung e.V., Berlin, 1980, 4 pp.

2.5. Gardner, N.J., "Pressure of Concrete on Formwork—A Review," ACI JOURNAL, *Proceedings* V. 82, No. 5, Sept.-Oct. 1985, pp. 744-753.

2.6. Grundy, Paul, and Kabaila, A., "Construction Loads on Slabs with Shored Formwork in Multistory Buildings," ACI JOURNAL, *Proceedings* V. 60, No. 12, Dec. 1963, pp. 1729-1738.

2.7. Agarwal, R.K., and Gardner, Noel J., "Form and Shore Requirements for Multistory Flat Slab Type Buildings," ACI JOURNAL, *Proceedings* V. 71, No. 11, Nov. 1974, pp. 559-569.

2.8. Noble, John, "Stop Guessing at Reshore Loads—Measure Them," *Concrete Construction*, V. 20, No. 7, July

1975, pp. 277-280.

CHAPTER 3—CONSTRUCTION

3.1—Safety precautions

Constructors should follow all state, local, and federal codes, ordinances, and regulations pertaining to forming and shoring.

In addition to the very real moral and legal responsibility to maintain safe conditions for workmen and the public, safe construction is in the final analysis more economical than any short-term cost savings from cutting corners on safety provisions. Attention to safety is particularly significant in formwork construction as these structures support the concrete during its plastic state and as it is developing strength, until the concrete becomes structurally self-sufficient. Following the design criteria contained in this guide is essential to assuring safe performance of the forms. All structural members and connections should be carefully planned so that a sound determination of loads may be accurately made and stresses calculated.

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

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

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

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 form watchers during concrete placement to assure early recognition of possible form displacement or failure. A supply of extra shores or other material and equipment that might be needed in an emergency should be readily available.

c) Provision for adequate illumination of the formwork.

d) Inclusion of lifting points in the design and detailing of all forms which will be crane-handled. This is especially important in flying forms or climbing forms. In the case of wall formwork, consideration should be given to an independent scaffold bolted to the previous lift.

e) Incorporation of scaffolds, working platforms, and guardrails into formwork design and all formwork drawings.

f) A program of field safety inspections of formwork.

3.1.1 Some common construction deficiencies which may lead to form failures are these, which are applicable to all formwork:

a) Failure to inspect formwork during and after concrete placement to detect abnormal deflections or other signs of imminent failure which could be corrected.

b) Insufficient nailing, bolting, 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) Lack of proper field inspection by qualified persons to assure that form design has been properly interpreted by form builders.

g) Use of lumber containing knots that impair the strength of the member.

h) Improper welding of structural components.

3.1.2 Construction deficiencies applicable to vertical formwork include:

a) Failure to control rate of placing concrete vertically without regard to design parameters.

b) Inadequately tightened or secured form ties or hardware.

c) Form damage in excavation by reason of 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 constructed or located pouring pockets.

h) Inadequate bulkheads.

i) Improperly anchored top forms on a sloping face.

j) Failure to provide adequate support for lateral pressures on formwork.

k) Attempt to plumb forms against concrete pressure force.

3.1.3 Construction deficiencies applicable to horizontal forms for suspended structures include:

a) Improper use of multi-tier shores.

b) Failure to regulate properly the rate and sequence of placing concrete horizontally to avoid unanticipated loadings on the formwork.

c) Shoring not plumb, thus inducing lateral loading as well as reducing vertical load capacity.

d) Locking devices on metal shoring not locked, inoperative, or missing.

e) Vibration from adjacent moving loads or load carriers.

f) Inadequately tightened or secured shore hardware or wedges.

g) Loosening of reshores or backshores under floors below.

h) Premature removal of supports, especially under cantilevered sections.

i) Inadequate bearing or unsuitable soil under mudsills (Fig. 3.1.3a).

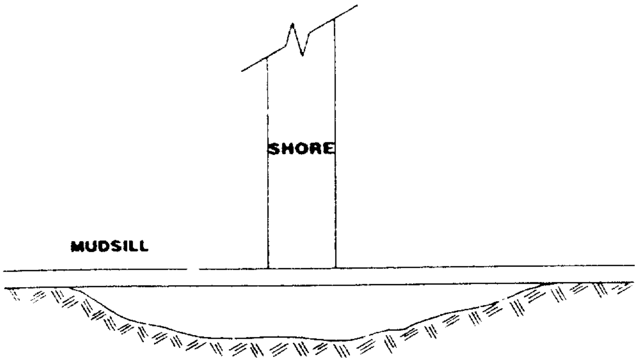

Fig. 3.1.3a—Inadequate bearing under mudsill

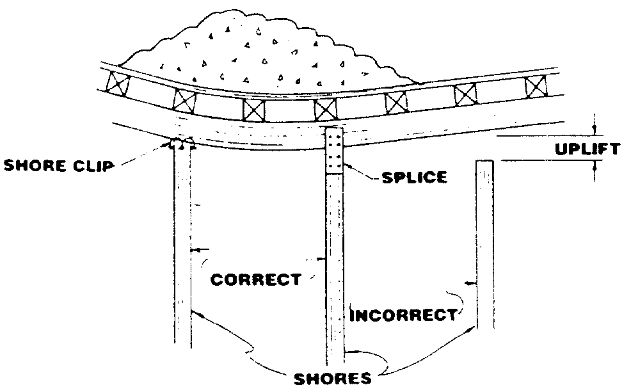

Fig. 3.1.3b—Uplift of formwork. Connection of shores to joists and stringers must hold shores in place when uplift or torsion occurs. Lacing to reduce the shore or slenderness ratio may be required in both directions

j) Mudsills placed on frozen ground subject to thawing.

k) Connection of shores to joists, stringers, or wales which are inadequate to resist uplift or torsion at joints (see Fig. 3.1.3b).

l) Failure to consider effects of load transfer which may occur during post-tensioning (see Section 3.8.7).

m) Inadequate shoring and bracing of composite construction.

3.2—Construction practices and workmanship

3.2.1 *Fabrication and assembly details*

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

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

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

3.2.1.4 Use specified size and capacity of form ties or clamps.

3.2.1.5 Install and properly tighten all form ties or clamps as specified. All threads should fully engage the nut or coupling.

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

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

3.2.2 *Joints in the concrete*

3.2.2.1 Contraction joints, construction joints, and isolation joints should be installed as specified (see Fig. 3.2.2.1).

3.2.2.2 Bulkheads for control joints or construction joints should preferably be made by splitting along the lines of reinforcement passing through the bulkhead so that each portion may be positioned and removed separately without applying undue pressure on the reinforcing rods, which could cause spalling or cracking of the concrete. When required on the engineer/architect's drawing, beveled inserts at control joints must be left undisturbed when forms are stripped, and removed only after the concrete has been sufficiently cured. Wood strips inserted for architectural treatment should be kerfed to permit swelling without causing pressure on the concrete.

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

3.2.4 *Inspection*

3.2.4.1 Forms should be inspected and checked before the reinforcing steel is placed to insure that the dimensions and the location of the concrete members will conform to the drawings.

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

3.2.4.3 Forms should be checked for camber when specified.

3.2.5 *Cleanup and coatings*

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

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

3.2.6 *Construction operations on the formwork*

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

3.2.6.2 Runways for moving equipment should be provided with struts or legs as required and should be supported directly on the formwork or structural member. They should not bear on nor be supported by the reinforcing steel unless special bar supports are provided. The formwork must be suitable for the support of such

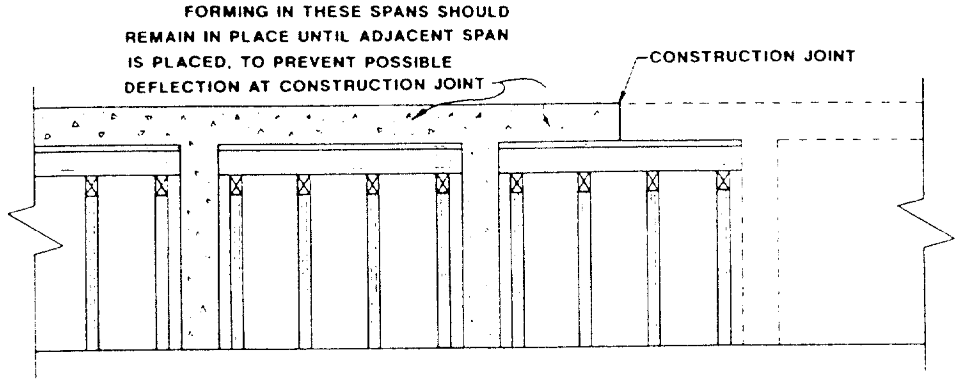

Fig. 3.2.2.1—Forming and shoring restraints at construction joints in supported slabs

runways without significant deflections, vibrations, or lateral movements.

3.2.7 *Loading new slabs* — Guard against overloading of new slabs. Loads such as aggregate, timber, boards, reinforcing steel, or support devices must not be placed on new construction in such manner as to damage or overload it.

Table 3.4—Permitted gradual or abrupt irregularities in formed surfaces

Class of surface			
A	B	C	D
⅛ in.	¼ in.	½ in.	1 in.

3.3—Tolerances

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

The contractor is expected to set and maintain concrete forms so as to insure completed work within the tolerance limits.

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

Contractors are expected, and should be required, to establish and maintain in an undisturbed condition until final completion and acceptance of a project, control points and bench marks adequate for their own use and for reference to establish tolerances. (This requirement may become even more important for the contractor's protection when tolerances are not specified or shown). The engineer/architect should specify tolerances or require performance within generally accepted limits. Avoid specifying tolerances more stringent than commonly obtained for a specific type of construction as this usually results in disputes among the parties involved. For example, specifying permitted irregularities more stringent than those allowed for a Class C surface (Table 3.4) is incompatible with most concrete joist construction techniques. Where a project involves features sensitive to the cumulative effect of generally accepted 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 controls. The contract specifications should clearly state that a permitted variation in one part of the construction or in one section of the specifications must 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 facade must be able to accommodate the tolerance range for the lateral alignment and elevation of the perimeter concrete members.

3.4—Irregularities in formed surfaces

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

Gradual irregularities should be checked with a 5-ft

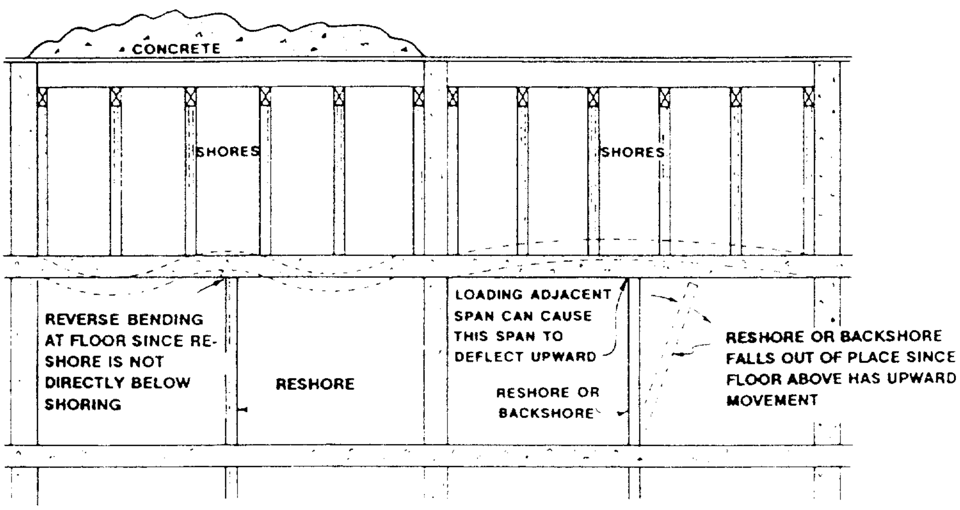

Fig. 3.5.1a—Reshore installation. Improper positioning of shores from floor to floor may create bending stresses for which the slab was not designed. If reshores do not match the shores above, then calculate for reversal stresses. Generally, the dead load stresses are sufficient to compensate for reversal stresses caused by reshores. Reshores must be prevented from falling

template, consisting of a straightedge for plane surfaces or a shaped template for curved or warped surfaces. In measuring irregularities, the straightedge or template may be placed anywhere on the surface in any direction.

Four classes of formed surface are defined in Table 3.4. The engineer/architect should indicate which class is required for the work being specified, or indicate other irregularity limits where needed.

Class A is suggested for surfaces prominently exposed to public view, where appearance is of special importance. Class B is intended for coarse-textured concrete formed surfaces intended to receive plaster, stucco, or wainscoting. Class C is a general standard for permanently exposed surfaces where other finishes are not specified. Class D is a minimum quality requirement for surfaces where roughness is not objectionable, usually applied where surfaces will be permanently concealed. Special limits on irregularities may be needed for surfaces continuously exposed to flowing water, drainage, or exposure. If permitted irregularities are different from those given in Table 3.4, they should be specified by the engineer/architect.

3.5—Shoring and centering

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

Shoring resting on intermediate slabs or other construction already in place need not be located directly above shores or reshores below unless the slab thickness and the location of its reinforcement are inadequate to take the reversal of stresses and punching shear. Where the latter conditions are questionable, the shoring location should be approved by the engineer/architect (see Fig. 3.5.1a).

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

Multi-tier shoring is not recommended and is considered a dangerous practice.

Where a slab load is supported on one side of the beam only (see Fig. 3.5.1b), edge beam forms should be carefully planned to prevent tipping of the beam due to unequal loading.

Vertical shores must be erected so that they cannot tilt, and must have firm bearing. Inclined shores must be braced securely against slipping or sliding. The bearing ends of shores should be square. Connections of shore heads to other framing should be adequate to prevent the shores from falling out when reversed bending causes upward deflection of the forms (see Fig. 3.1.3b).

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

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

3.6—Inspection and adjustment of formwork*

3.6.1 *Before concreting*

3.6.1.1 Telltale devices should be installed on shores

* Helpful information about forms before, during, and after concreting may be found in Reference 13 and the ACI *Manual of Concrete Inspection*, SP-2.

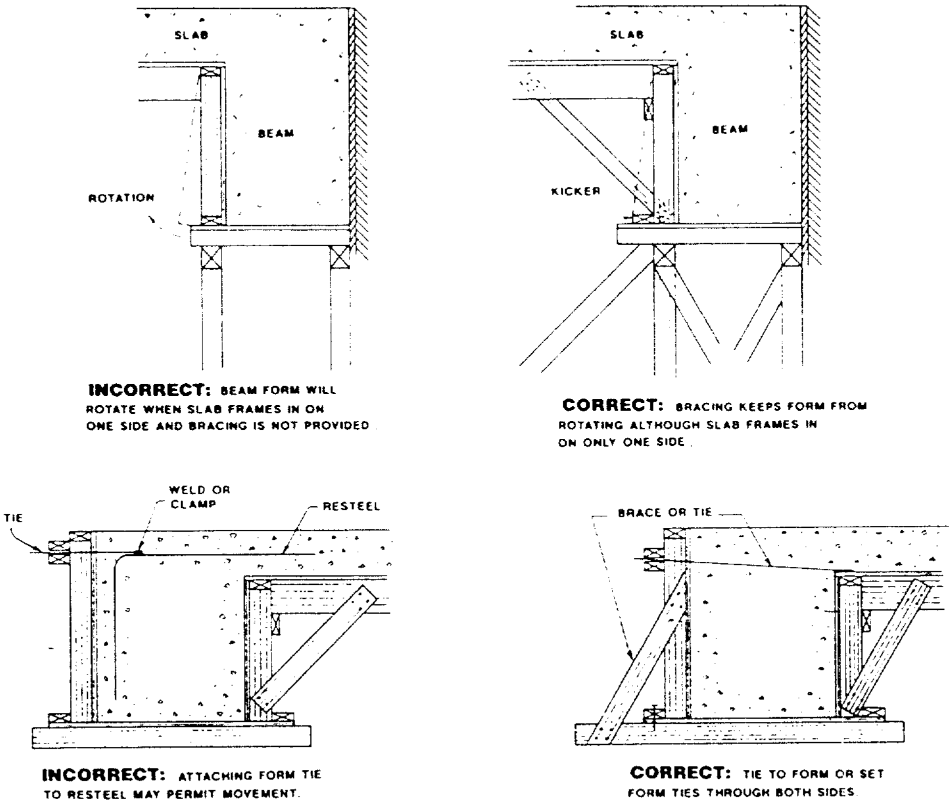

Fig. 3.5.1b—Prevention of rotation is important where the slab frames into the beam form on only one side

or forms to detect formwork movements during concreting.

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

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

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

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

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

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

3.7—Removal of forms and supports

3.7.1 *Discussion* — Although the contractor is generally responsible for design, construction, and safety of formwork, it is recommended that criteria for removal of forms or shores be specified by the engineer/architect.

3.7.2 *Recommendations*

3.7.2.1 The engineer/architect should specify the minimum strength of the concrete to be attained before removal of forms or shores. The strength may be determined by tests on job-cured specimens or on the in-place concrete. The engineer/architect should specify who will make the specimens and who will make the tests.

Results of such tests, as well as records of weather conditions and other pertinent information, should be recorded. Depending on the circumstances, a minimum elapsed time after concrete placement may be established for removal of the formwork.

Determination of the time of form removal should be based on the resulting effect on the concrete.* When forms are stripped there must be no excessive deflection or distortion and no evidence of damage to the concrete, due either to removal of support or to the stripping operation (Fig. 3.7.2.1). When forms are removed before the specified curing is completed, measures should be taken to continue the curing and provide adequate thermal protection for the concrete. Supporting forms and shores must not be removed from beams, floors, and walls until these structural units are strong enough to

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

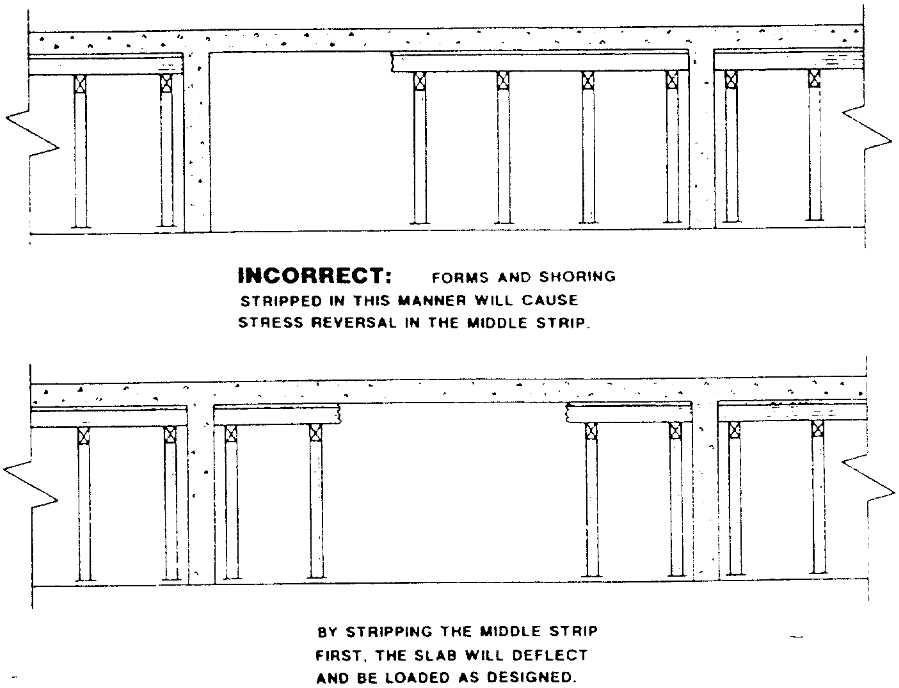

Fig. 3.7.2.1—Stripping sequence for two-way slabs

carry their own weight and any approved superimposed load. In no case should supporting forms and shores be removed from horizontal members before concrete strength is at least 70 percent of design strength, as determined by field-cured cylinders or other approved methods, unless approved by the engineer/architect.

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

3.7.2.2 When field operations are controlled by the engineer/architect's specifications, the removal of forms, supports, and protective enclosures, and the discontinuance of heating and curing must 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 which are not more favorable than the most unfavorable conditions for the portions of the concrete which the test specimens represent. The curing records may serve as the basis on which the engineer/architect will determine his approval of form stripping.

3.7.2.3 Since the minimum stripping time is a function of concrete strength, the preferred method of determining stripping time is by the use of tests of job-cured specimens or of the concrete in place. However, when the engineer/architect does not specify minimum strength required of concrete at the time of stripping, the following elapsed times may be used under ordinary conditions. The times shown represent cumulative number of days, or hours, not necessarily consecutive, during which the temperature of the air surrounding the concrete is above 50 F. If high-early-strength concrete is used, these periods may be reduced as approved by the engineer/architect. Conversely, if ambient temperatures remain below 50 F, or if retarding agents are used, then these periods should be increased at the discretion of the engineer/architect.

Walls*	12 hr
Columns*	12 hr
Sides of beams and girders*	12 hr
Pan joist forms†	
30 in. wide or less	3 days
Over 30 in. wide	4 days

	Structural live load less than structural dead load	Structural live load more than structural dead load
Arch centers	14 days	7 days
Joist, beam or girder soffits		
Under 10 ft clear span between structural supports	7 days‡	4 days
10 to 20 ft clear span between structural supports	14 days‡	7 days
Over 20 ft clear span between structural supports	21 days‡	14 days

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

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

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

One-way floor slabs		
Under 10 ft clear span between structural supports	4 days*	3 days
10 to 20 ft clear span between structural supports	7 days*	4 days
Over 20 ft clear span between structural supports	10 days*	7 days

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

Post-tensioned slab system† .... As soon as full post-tensioning has been applied.

3.8—Shoring and reshoring of multistory structures

3.8.1 *Discussion* — Multistory work represents special conditions, particularly in relation to removal of forms and shores. Reuse of form material and shores is an obvious economy. Furthermore, the speed of construction customary in this type of work provides the additional advantage of permitting other trades to follow concreting operations from floor to floor as closely as possible. However, the shoring which supports green concrete is necessarily supported by lower floors which may not be designed for these loads. For this reason shoring or reshoring must be provided for a sufficient number of floors to develop the necessary capacity to support the imposed loads without excessive stress or deflection.

Reshoring is a specific procedure used to distribute construction loads to the lower floors. Table 3.8.1 lists key features of reshoring.

For purposes of this discussion the following definitions apply:

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

Reshores — Shores placed snugly under a stripped concrete slab or structural member after the original forms and shores have been removed from a large area, thus requiring the new slab or structural member to deflect and support its own weight and existing construction loads applied prior to 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.

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

† See Section 3.8 for special conditions affecting number of floors to remain shored or reshored.

Table 3.8.1 — Key features of reshoring

RESHORING
Strip several entire bays.
Allow slab to deflect.
Install reshores without removing deflection.
Slabs carry their own weight.
Reshores have no initial load.

In a common method of analysis, while reshoring remains in place at grade level, each level of reshores carries the weight of only the new slab plus construction load. 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. Addition or removal of loads may be due to construction activity or to removing shores or reshores in the system. Shore loads are determined by equilibrium of forces at each floor level.

3.8.2 *Advantages of reshoring*

Reshores — Stripping formwork is more economically accomplished 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, thus reducing the load in the reshores. Reshoring usually requires fewer levels of interconnected slabs, thus freeing more areas for other trades. Near-capacity loads in slabs usually occur for only short periods.

3.8.3 *Other methods* — Other methods of supporting new construction are less widely used and involve leaving the original shores in place or replacing them individually (backshoring and preshoring) so as not to allow the slab to deflect and carry its own weight. These methods are not recommended unless performed under careful supervision by the Contractor and Engineer because excessively high slab and shore loads can develop.

3.8.4 *Design* — Refer to Chapter 2.

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

Reshoring is one of the most critical operations in formwork; consequently the procedure should be planned in advance and should be reviewed or approved by the engineer/architect. Operations should be performed so that at no time will areas of new construction be required to support combined dead and construction loads in excess of their capability as determined by design load and developed concrete strength at the time of stripping and reshoring.

In no case should shores be so located as to significantly alter the pattern of stress determined in the structural analysis or to induce tensile stresses where reinforcing bars are not provided. Size and number of shores, and bracing if required, must provide a supporting system capable of carrying any loads that may possibly be imposed on it.

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

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

When placing reshores, care should be taken not to preload the lower floor and also not to remove the normal deflection of the slab above. The reshore is simply a strut and should be tightened only to the extent that no significant shortening will take place under load.

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

3.8.7 *Post-tensioning effects on shoring and reshoring* — The design and placement of shores and reshores for post-tensioned construction requires more consideration than for normal reinforced concrete. The stressing of post-tensioning steel can cause overloads to occur in shores, reshores, or other temporary supports. The stressing sequence appears to have the greatest effect. When a slab is post-tensioned, the force in the tendon produces downward load at the beam. If the beam is shored, the shoring must carry this added load. Magnitude of the load may approach the dead one-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.

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

CHAPTER 4—MATERIALS FOR FORMWORK

4.1—General

The selection of materials suitable for formwork should be based on economy to the contractor, consistent with safety during construction and the quality required in the finished work. Approval by the engineer/architect, if required by the contract documents, should be based on quality of finished work. Where concrete surface aesthetics are critical, the architect/engineer should give special notice and make provision for preconstruction mock-ups. See Chapter 5 for architectural concrete provisions.

4.2—Properties of materials

4.2.1 *General* — ACI publication SP-4, *Formwork for Concrete*[1.3] describes the formwork materials commonly used in the United States and provides extensive related data for form design. Much useful specification and design information is also available from manufacturers and suppliers of materials. Table 4.2 indicates other 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 which can meet quality and safety requirements established for the finished work.

4.2.2 *Sheathing* — Sheathing is the supporting layer of formwork closest to the concrete. It may be in direct contact with the concrete or be separated from it by a form liner. Sheathing consists of wood, plywood, metal, or other materials capable of transferring the load of the concrete to supporting members such as joists or studs.

In selecting and using these materials, important considerations are: (1) strength; (2) stiffness; (3) release; (4) reuse and cost per use; (5) surface characteristics imparted to the concrete such as wood grain transfer, gloss, paintability; (6) resistance to mechanical damage, such as from vibrators and abrasion from slipforming; (7) workability for cutting, drilling, and attaching fasteners; (8) adaptability to weather and extreme field conditions, temperature, and moisture; and (10) weight and ease of handling.

4.2.3 *Structural supports* — Structural support systems carry the sheathing. Important considerations are: (1) strength; (2) stiffness; (3) dimensional accuracy and stability; (4) workability for cutting, drilling, and attaching fasteners; (5) weight; (6) cost and durability.

4.3—Accessories

4.3.1 *Form ties* — A form tie is a tensile unit used to hold concrete forms against the active pressure of freshly placed plastic concrete. In general, it consists of an inside tensile member and an external holding device, both made to specifications of various manufacturers. These manufacturers also publish recommended working loads on the ties for use in form design. There are two basic types of tie rods, the prefabricated rod or band type, and

Table 4.2 — Form materials with data sources* for design and specification

Item	Principle use	Reference data
Sawn lumber	Form framing, sheathing, and shoring	"American Softwood Lumber," PS20 National Design Specification for Wood Construction (NFPA) *Wood Handbook: Wood as an Engineering Material*, Reference 4.3 *Manual for Wood Frame Construction*, Reference 4.4 *Wood Engineering*, Reference 4.5 *Timber Construction Manual*, Reference 4.6
Engineered wood	Form framing and sheathing	"Code for Engineering Design in Wood" (Canada), CAN3-086 "Concrete Forms," Reference 4.7
Plywood	Form sheathing and panels	"Construction and Industrial Plywood," PS1 "Plywood Design Specification," Reference 4.8 "Plywood Design Specification," APA
Steel	Panel framing and bracing Heavy forms and falsework Column and joist forms	*Manual of Steel Construction*, Reference 4.9 *Cold-Formed Steel Design Manual*, Reference 4.10 "Forms for One-Way Concrete Joist Construction," ANSI A48.1 "Forms for Two-Way Concrete Joist Construction," ANSI A48.2 "Code of Standard Practice for Concrete Joist Construction," part of Reference 4.1
	Stay-in-place forms	ASTM A 446 (galvanized steel)
Aluminum†	Lightweight panels and framing; bracing and horizontal shoring	*Aluminum Construction Manual*, Reference 4.11
Reconstituted wood panel products‡	Form liner and sheathing	"Mat-Formed Wood Particle-board," ANSI A208.1 "Hardboard Concrete Form Liners," LLB-810a
Insulating board, wood or glass fiber	Stay-in-place liners or sheathing	ASTM C 532 (insulating formboard)
Fiber or laminated paper pressed tubes or forms	Column and beam forms; void forms for slabs, beams, girders, and precast piles	
Corrugated cardboard	Internal and under-slab voids; voids in beams and girders (normally used with internal "egg crate" stiffeners)	"A Study of Cardboard Voids for Prestressed Concrete Box Slabs," Reference 4.12
Concrete	Footings, stay-in-place forms, molds for precast units	ACI 318 "Precast Concrete Units Used as Forms for Cast-in-Place Concrete," ACI 347.1R
Fiberglass-reinforced plastic	Ready-made column and dome pan forms; custom-made forms for special architectural effects	"Reinforced Plastic Forms for Concrete," Reference 4.13 *Plastic Laminate Materials, Their Properties and Usage*, Reference 4.14
Cellular plastics	Form lining and insulation; permanent forms	"Cellular Plastics in Construction," Reference 4.15 "Cellular Plastics for Building," Reference 4.16
Other plastics: Polystyrene, Polyethylene, Polyvinyl chloride	Form liners for decorative concrete	
Rubber	Form lining and void forms	
Form ties, anchors and hangers	For securing formwork against placing loads and pressures	See Section 2.4 for recommended safety factors
Plaster	Waste molds for architectural concrete	
Coatings	Facilitate form removal	
Steel joints	Formwork support	"Standard Specifications and Load Tables for Open Web Steel Joists," Reference 4.17
Steel frame shoring	Formwork support	"Recommended Horizontal Shoring Beam Erection Procedure," Reference 4.18 "Recommended Safety Requirements for Shoring Concrete Formwork," Reference 4.19 *Design Manual for Structural Tubing*, Reference 4.20
Form insulation	Cold weather protection of concrete	ACI 306R; see also *"Cellular Plastics"*

* In addition to ACI Special Publication No. 4, *Formwork for Concrete*. Handbooks, standards, and specifications cited here are listed in Chapter 4 references or Chapter 8.
† Shall be readily weldable, nonreactive to concrete or concrete containing calcium chloride, and protected against galvanic action at points of contact with steel.
‡ Check surface reaction with wet concrete.

the threaded internal disconnecting type. Their suggested working loads range from 1000 to over 50,000 lb.

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

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

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

4.3.5 *Recommendations*

4.3.5.1 Recommended factors of safety for ties, anchors, and hangers are given in Section 2.4. Yield point of the material should not be exceeded.

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

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

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

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

4.3.5.3 Form hangers must support the dead load of forms, weight of concrete, and construction and impact loads. Form hangers should be symmetrically arranged on the supporting member and loaded, through proper sequencing of the concrete placement, to minimize twisting or rotation of the hanger or supporting members.

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

4.4—Form coatings and release agents

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

a) Alter the texture of the contact surface.
b) Improve the durability of the contact surface.
c) To facilitate release from concrete during stripping.
d) Seal the contact surface from intrusion of moisture.

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

4.4.3 *Manufacturers' recommendations* — Manufacturers' recommendations should be followed in the use of coatings, sealers, and release agents, but independent investigation of their performance is recommended before use. 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, bonding of subsequent concrete placements must be considered.

4.5—References

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4.3. *Wood Handbook: Wood as an Engineering Material*, Forest Products Laboratory, Prentice Hall, 1990.

4.4. *Manual for Wood Frame Construction*, National Forest Products Association, Washington, D.C., 1988.

4.5. Gurfinkel, German, *Wood Engineering*, Kendall Hunt Publishing Co., Dubuque, 1981, 552 pp.

4.6. American Institute of Timber Construction, *Timber Construction Manual*, 3rd Edition, John Wiley & Sons, New York, 1986, 836 pp.

4.7. "Concrete Forms," Western Wood Products Association, Portland, Oregon.

4.8. "Plywood Design Specification," with supplements, American Plywood Association, Tacoma, WA, 1990.

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4.10. *Cold-Formed Steel Design Manual*, American Iron and Steel Institute, New York.

4.11. *Aluminum Construction Manual*, Aluminum Association, New York.

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

4.13. Ziverts, George J., "Reinforced Plastic Forms for Concrete," *Proceedings*, 21st Annual Meeting, Society of the Plastics Industry, New York, 1966.

4.14. Beach, Norman E., *Plastic Laminate Materials, Their Properties and Usage*, Foster Publishing Co., Long Beach, Calif.

4.15. "Cellular Plastics in Construction," Building Materials Committee, Cellular Plastics Division, Society of the Plastics Industry, New York.

4.16. "Cellular Plastics for Building," *Digests* 93 and 94, Building Research Station, Garston, Watford, May and June 1968. (Available from Her Majesty's Stationery Office, London).

4.17. "Standard Specifications and Load Tables for Open Web Steel Joists," Steel Joist Institute, Arlington, Va.

4.18. "Recommended Horizontal Shoring Beam Erection Procedure," Scaffolding, Shoring, and Forming Institute, Cleveland.

4.19. "Recommended Safety Requirements for Shoring Concrete Formwork," Scaffolding, Shoring, and Forming Institute, Cleveland.

4.20. *Design Manual for Structural Tubing*, Committee of Steel Pipe Producers, American Iron and Steel Institute, New York, 1974, 111 pp.

CHAPTER 5—ARCHITECTURAL CONCRETE

5.1—Introduction

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

This chapter identifies and emphasizes additional factors that may have a critical influence on formwork for cast-in-place architectural concrete. Tilt-up and other types of precast architectural concrete are not considered here.

5.1.2 *Definition* — Architectural concrete is defined as concrete that is exposed as an interior or exterior surface in the completed structure, definitely contributes to its visual character, and is specially designated as such in the contract documents. Particular care must be taken in the selection of materials for and in the design and construction of the formwork, as well as in the placing and consolidation of such 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 must also be considered when the form materials are selected. Special attention should be given to closure techniques, concealment of joints in formwork materials, and to the sealing of forms to make them watertight.

5.1.3 *Factors in addition to formwork* — Many factors other than formwork affect the architectural effects achieved in concrete surfaces. They start at the design stage and carry through to the completed project. Factors affecting the concrete can also include the mix design or aggregate, the method of placing the concrete, and the consolidation technique. Chemicals may have an effect on the final product, whether used as additives in the mix; 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 as well as other influencing factors must be identified and their effects evaluated during the initial design stages. However, the single most important factor for success of an architectural concrete job is good workmanship.

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

5.2—Role of the architect

5.2.1 *Preplanning* — Much architectural concrete is also structural, but the quality of surface generally desired for architectural concrete is of a different level from that which is satisfactory for structural concrete, and is therefore more costly. The architect who keeps abreast of the state of the art in forming and concrete technology can use this information during the design process to keep his plans in line with the budget for the structure. Intricacies and irregularities may be costly far out of proportion to their esthetic contribution. For economy, the architect can make form reuse possible by standardizing building elements such as columns, beams, windows, and by making uninterrupted form areas the same size wherever possible to facilitate use of standard form gangs or modules. Increased size of these uninterrupted areas will contribute to forming economy. A prebid conference with qualified contractors will bring out many practical considerations before the design is finalized.

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

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

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

5.2.3 *Tolerances* — The architect should specify dimensional tolerances considered essential to successful execution of the design. ACI 117 can be consulted, but the architect must realize that the tolerances therein are for concrete construction in general, and more restrictive tolerances may be required for architectural work. No numerical limits are suggested here since the texture, lighting, and configuration of surfaces will all have an influence.

5.2.4 *Camber* — The builder can be expected to camber forms to compensate for deflection of the forms themselves during construction. However, the architect must specify any additional camber required to compensate for structural deflection or optical sag (the illusion that a perfectly horizontal long span member is sagging). The architect should be aware that it is customary to check horizontal members for compliance with tolerances before removal of forms and shores.

5.2.5 *Joints and details* — Location, number, and details of such items 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.* Since 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 esthetically satisfactory, dummy joints can be introduced to give a smaller pattern. Actual joints between sheathing materials can be masked by means of rustication strips (splayed fillets) attached to the form face. Rustication strips at horizontal and vertical construction joints can also create crisp edges accented by shadow lines instead of the potential ragged edge of a construction joint left exposed to full view.

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

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

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

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

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

5.3—Materials and accessories

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

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

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

5.3.4 *Form ties* — Form tie assemblies for architectural concrete should permit tightening of forms and be of such type as to leave no metal closer to the surface than 1½ in. for steel ties and 1 in. for stainless steel ties. They 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 otherwise specified. Ties should be tight fitting or holes sealed to prevent leakage at the holes in the form. If textured surfaces

* Some guidance on joint locations can be found in ACI 224R, 303R, and 332R.

are to be formed, ties should be carefully evaluated as to fit, pattern, grout leakage, and esthetics.

5.3.5 *Side form spacers* — Side form spacers, as defined in Section 4.3.4, are particularly important in architectural concrete to maintain adequate cover over reinforcing steel and prevent development of rust streaking on concrete surfaces. Plastic, plastic-protected, rubber-tipped, or other noncorroding spacers must 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 must be adequate for job conditions. However, they should never be more than 6 ft on centers, and always staggered.

5.4—Design

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

5.4.2 *Lateral pressure of concrete* — Architectural concrete may be subjected to external vibration, revibration, set retardants, superplasticizers, and slumps greater than those assumed for determining the lateral pressure as noted in Section 2.2.2. Particular care must be exercised in these cases to design the forms for the increased lateral pressures arising from the aforementioned sources as noted in Section 2.2.2.

5.4.3 *Structural considerations* — Since deflections in the contact surface of the formwork reflect directly in finished surfaces under varying light conditions, forms for architectural concrete must be designed carefully to minimize deflections. Deflections may govern design rather than bending (flexural stress) or horizontal shear. Deflections of sheathing, studs, and wales should be designed so that the finished surface meets the architectural specifications. Wood forms bow with reuse, and hence more bulging will be reflected in the surface formed after several uses. This effect should be considered when designing wood forms.

When tie size and spacing are limited by the architect, the form designer 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, he can find the allowable pressure, design supporting members, and establish a rate of placing.

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

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

Externally braced forms may be used instead of any of the above mentioned methods to avoid objectionable blemishes in the finished surface. However, externally braced forms may be more difficult and more costly to build.

Consideration should be given to re-anchoring forms into preceding or adjacent pours to achieve a tight fit and prevent grout leakage at these points. Ties should be located within 18 in. of the construction joint wherever possible to facilitate re-anchoring the form to adjacent pours. Sheathing should not overlap the adjacent pour by more than 1½ in.

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

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

5.4.6 *Tolerances* — The form designer must check for specified dimensional tolerances that may have a bearing on what deflections can be permitted when designing the forms. If no special tolerances are given, the form designer may use ACI 117 tolerances for structural concrete.

5.5—Construction

5.5.1 *General* — Forms should be carefully built to resist the pressures to which they will be subjected and to limit deflections to a practicable minimum within the tolerances specified.

Joints in structural members should be kept to a minimum, and where necessary, should be suitably spliced or otherwise constructed so as to maintain continuity.

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

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

Where special forming systems are specified by the engineer for structural purposes (such as one-way 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 which are to be reused should be carefully inspected after each use to assure that they have not become damaged, distorted, disassembled, or otherwise unable to perform as designed.

5.5.2 *Sheathing and jointing* — Contact surfaces of the formwork should be carefully installed to produce neat and symmetrical joint patterns unless otherwise specified. Joints should be either vertical or horizontal and, where possible, should be staggered so as 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. Box nails should be used when required on the contact surface and should be placed in a neat pattern.

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

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

Architectural concrete forms should be leakproof. One method to prevent loss of water 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.

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

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

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

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

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

5.5.4 *Ornamental liners and detail* — Ornamental concrete usually is 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 may become wedged between projections in the ornament. Molds must be so constructed that joints will not be opened by slight movement or swelling of the wood. Joints in the molds should be made inconspicuous by pointing.

The molds should be carefully set in the forms and securely held in position to reproduce the design shown on the drawings. Where wood forms adjoin molds, the wood should be neatly fitted to the profile of the mold and all joints should be carefully pointed. The molds and the adjacent wood forms should be so detailed that the wood forms can be stripped without disturbing the molds. A slight draft on the edge of molds or pattern strips should be provided to permit removing the detail material without damaging the concrete. Special provisions should be made for early form removal and/or retardation 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 be sound to hold the fasteners. When gluing, the surfaces should be cleaned and dried thoroughly so that the glue will bond. Do not use glue at temperatures lower than those recommended by the manufacturer.

5.6—Form removal

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

Once formwork is removed, the architectural surfaces must be protected from continuing construction operations.

5.6.2 *Concrete strength* — It is desirable for architectural concrete to have a higher compressive strength than normal for stripping. This can be accomplished by adjusting the mix 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 may scale or spall. Thus, a good quality surface might require the forms to stay in place longer. However, the longer the forms stay in place, the darker the concrete will become. The architect/engineer should specify what concrete strength is required before stripping can take place.

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

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

CHAPTER 6—SPECIAL STRUCTURES

6.1—Discussion

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

6.2—Bridges and viaducts, including high piers

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

6.2.2 *Shoring and centering* — Follow recommended practice in Sections 3.5 and 3.7 for erection and removal. 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.

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

6.3—Structures designed for composite action

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

Shoring, with or without cambering of 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 may be imposed before the concrete attains its design strength.

6.3.2 *Design* — Formwork members and shores should be designed to limit deflections to a practical minimum consistent with the structural member being constructed.

Where camber is specified for previously installed components of the structure, allowance should be made for the resultant preloading of the shores before application of the dead load of concrete.

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

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

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

6.3.3 *Erection* — Construction and/or erection of formwork for composite construction follows basic recommendations contained in Chapter 3. Shoring of members that will act compositely with the concrete to be placed should be done with great care to assure sufficient bearing, rigidity, and tightness so as to prevent settlement or deflections beyond allowable limits. Wedges, shims, jacks, etc., should be provided to permit adjustment if required before or during concreting as well as to permit removal without jarring or impact of 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 the pour, it is not recommended. Any required adjustment should be made prior to initial set of the concrete.

Where camber is required, distinction should be made between that part which is an allowance for settlement or deflection of formwork or shoring and that which is provided for design loadings. The former should generally be the responsibility of the 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 [see also Section 1.4.5(f)].

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

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

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

6.4.2 *Design*

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 drawing with the bidding documents as a basis for the design of the forming and support system to be used by the contractor.

c) Lateral loads—In determining the lateral forces acting on the formwork, the wind load should be calculated on the basis of a minimum of 15 psf of projected vertical area as specified for wall forms in Section 2.2.3. For structures such as domes, negative forces due to suction created by the wind on the leeward side of the structure should be considered.

d) Analysis—The provisions of Sections 2.1.1 and 2.3 should be closely adhered to in such formwork planning.

Assumed design loads should be shown on the formwork drawings. Complete stress analyses should be prepared by competent structural engineers, and the maximum and minimum values of stress, including reversal of stress, should be shown for each member for the most severe loading conditions. Due regard 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 insure that the formwork will function satisfactorily and that the concrete tolerances will be met.

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

Since the weight of the formwork may, in many cases, be equal to or greater than the design live load of the structure, form details should be so designed as to avoid hanging up the formwork and thus overloading the structure itself during decentering.

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

6.4.3 *Drawings* — When required, the 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 insure that the structure can assume its deflected shape without damage, the decentering or handling sequence of the formwork should be shown on the drawings.

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

6.4.4 *Approval* — The formwork drawings and procedures must comply with federal and local safety laws as well as with the contract drawings and specifications and meet the general requirements for formwork to assure the integrity and stability of the permanent structure itself. The engineer/architect should check the design and shop drawings for the formwork to insure that these requirements are met and approve them in writing.

6.4.5 *Construction* — In planning and erecting formwork, provision should be made for adequate means of adjustment during placing where necessary. Telltales should be installed to check alignment and grade during placement.

Where the forming system is based on a certain placing sequence, that sequence should be clearly defined and adhered to in the field.

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

6.5—Mass concrete structures

6.5.1 *Discussion* — ACI 116R defines mass concrete as "any volume of concrete with dimensions large enough to require that measures be taken to cope with generation of heat from hydration of the cement and attendant volume change to minimize cracking." Mass concrete generally 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. Special provisions usually are made to control the temperature rise in the mass by the use of cement or cementing material combinations possessing low or moderate heat-generating characteristics, by postcooling, cooling the fresh concrete, or by placing sequence.

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

6.5.2 *Lateral pressure of concrete* — The lateral pressure formulas for concrete placed in walls may be used for mass concrete. See Section 2.2.2.

Consideration should be given to placing sequence in the determination of pressure. Frequently, concrete is layered in such a way that a full liquid head is developed against the form on the closure end. In addition, the use of large concrete buckets may cause high impact loads near the forms.

6.5.3 *Design considerations* — Particular care must be taken to provide anchorage for forms with a batter and wall forms tied to a rock face. The ultimate strength of the tie rods must not exceed the ultimate strength of the anchor bar or bolt. The bending and welding of high tensile steel tie rods should be prohibited. Consideration should be given to form ties embedded in previously placed concrete to insure that such concrete has attained sufficient strength to sustain design loadings from the new placement as well as initial bolting stresses.

6.5.4 *Tolerances* — See Section 3.3 and ACI 117.

6.6—Underground structures

6.6.1 *Discussion* — Underground structures differ from corresponding surface installations in that the construction takes place inside an excavation instead of in the open, thereby providing unique problems in handling and supporting formwork and in the associated concrete placing. As a result, the following four factors usually make the design of formwork for underground structures entirely different than for their aboveground counterparts: First, concrete to fill otherwise inaccessible areas may be placed pneumatically or by positive displacement pump and pipeline; second, the rock sometimes is utilized as a form backing, thereby permitting the use of rock anchors and tie rods in lieu 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 sometimes can be used for attaching hoisting devices.

When placement is 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, see ACI 304.2R.

6.6.2 *Design loads*

6.6.2.1 *Vertical loads* — Vertical and construction loads assumed in 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 of flotation effect beneath tunnel forms.

In placing concrete in the crowns of tunnel forms, pressures up to 3000 psf have been induced in areas of overbreak and near vertical bulkheads from concrete placed pneumatically or by positive displacement pump. Until more definite recommendations can be made, the magnitude and distribution of pressure should be determined by the design engineer. In no case should the assumed pressure be less than 1000 psf acting normally to the form plus the dead weight of the concrete placed pneumatically or by pump.

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

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

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

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

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

6.6.3.2 Recommended method of supplemental strutting or bracing to be employed in areas where form pressures may exceed those just listed due to abnormal conditions.

6.6.3.3 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.

6.6.3.4 In the case of the tunnel arch form, whether it is intended for use with the unit or bulkhead system of concrete placement or is restricted to use with the continuously advancing slope method (see Section 6.6.4).

6.6.3.5 When placement of concrete by pumping or pneumatic methods is anticipated, the capacity and working pressure of the prime mover and the size, length, and maximum embedment of the discharge line should be as assumed in the design. Also, when the design provides for a method of placement other than by sustained pumping via a buried slick line, it should be clearly stated that the design pressures would be exceeded if sustained pumping were adopted.

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

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

The arch form for the bulkhead method is usually fabricated into a single unit between 50 and 150 ft 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 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 usually is established on the basis of experience, it can be safely predetermined by tests. It is recommended that at the start of a tunnel arch concreting operation, the minimum stripping time be 12 hr for exposed surfaces and 8 hr for construction joints. If the specifications provide for a reduced minimum stripping time based on site experience, such reductions should be in time increments of 30 min or less and should be established by laboratory tests and visual inspection and surface scratching of sample areas exposed by opening the form access covers. Arch forms should not be stripped prematurely when unvented ground water seepage could become trapped between the rock surface and the concrete lining.

6.6.5 *Materials* — The choice of materials for underground formwork usually is 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 of paramount importance 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 usually required.

When reuse is not a factor, plywood and tongue-and-groove lumber sometimes are used for exposed surface finishes, but more consideration may be given to wood sheathing because the high humidity often precludes the normal shrinkage and warping.

CHAPTER 7—FORMWORK FOR SPECIAL METHODS OF CONSTRUCTION

7.1—Recommendations

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

7.2—Preplaced aggregate concrete

7.2.1 *Discussion* — Preplaced aggregate concrete is made by injecting (intruding) mortar into the voids of a preplaced mass of clean, graded aggregate. For normal construction, the preplaced aggregates are 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 a dense concrete having 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 coarse aggregate is similar to coarse aggregate for conventional concrete. It is well washed and graded from ½ in. to the largest size practicable. After compaction in the forms, it usually has a void content ranging from 35 to 45 percent. Refer to ACI 304.1R.

7.2.2 *Design considerations* — Due to the method of placement, the lateral pressures on formwork are considerably higher than those developed for conventional concrete as given in Section 2.2.2. The form designer should be alerted to the unique problems created by high-density concrete, by mass placings where heat of hydration and drying shrinkage are critical, and by differential pressures in the form structure when mortar injection varies greatly from one form face to another.* Because of the pressure created during aggregate packing and mortar pumping, forms must be anchored and braced far more securely than for ordinary concrete. Particular attention must be paid to uplift pressures created in battered forms. Provision must be made to prohibit even the slightest uplift of the form. Injection pipes spaced 5 to 6 ft 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.

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; and

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* For additional information see ACI 359, ACI 207.1R, and *Concrete for Nuclear Reactors*, ACI Special Publication, No. 34.

b) The lateral pressure of the injected mortar; as an equivalent fluid the mortar normally weighs 130 lb per cu ft, but may weigh as much as 200 lb per cu ft for high-density mortars.

The time required for the initial set of the mortar (from 6 to 7 hr) and the rate of rise (1 to 6 ft per hr) 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 per hr) and the time of initial set in hours.

The lateral pressure for the design of formwork at any point is the sum of the pressures determined from Steps (a) and (b) for the given height.

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

The increased lateral pressure usually requires that the workmanship and details of formwork be of better quality than formwork for conventional concrete.

7.2.4 *Materials for formwork* — Tongue-and-groove lumber is preferred for exposed surfaces; the joints between boards permit the escape of traces of mortar. However, excessive bleeding will cause sand streaking, which will mar the appearance of the finished surface. When excessive bleeding is evident, caulking or sealing of the joints is recommended. For unexposed surfaces, mortar-tight forms of steel or plywood are acceptable. Prefabricated panel-type forms usually are not suitable because of the difficulty in making mortar-tight seals between panels. 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 employed for insuring a voidfree finished surface.

7.3—Slipforms*

7.3.1 *Discussion* —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 that the forms leave the concrete only after it is strong enough to retain its shape while supporting its own weight and the lateral forces caused by wind and equipment. Formwork of this type is frequently used for vertical structures such as silos, storage bins, building cores, bearing wall buildings, piers, chimneys, shaft linings, communication and observation towers, nuclear shield walls and similar structures.

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

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

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

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

7.3.2 *Vertical slipforms*

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

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

Wales have three main functions:

1. They support and hold the sheathing in place.
2. They transmit the lifting force from the yokes to the sheathing and to the other elements of the form.
3. They provide support for various platforms and scaffolding.

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

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

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

7.3.2.2 *Design and construction considerations* — Slipforms should be designed by experienced, competent engineers familiar with slip form construction. Construction of the slipform and the slipping operation should be carried out under the immediate supervision of a person or persons experienced in slipform work.

7.3.2.2.1 *Sheathing* — A form height of 3 ft. 6 in. is considered a minimum* and is usually constructed of

* For silo construction refer to ACI 313.

* The minimum height is a function of the rate of slipping (ft per hour) and the time required for the concrete to gain sufficient strength to support itself without sagging after leaving the slipform. A slightly higher form will provide some working space in the top of the form for placing of concrete and reinforcement. Forms less than 3½ ft high are believed to be dangerously shallow. Forms as high as 5 ft may be required when low temperature or slow setting concrete is specified. Forms in excess of 6 ft high can be used in special applications such as piers and single-sided shaft slipforms.

at least a nominal 1-in. board (tongue and groove preferred), ⅝-in. plywood with suitable backup wood elements, 10-gage minimum steel sheets, or other appropriate materials. Caution should be exercised when using steel sheets in extremes of heat or cold due to their lack of insulating capability. Both plywood and boards should be designed with their face grain running vertically. The 1-in. boards should be spaced 1/16 to ⅛ in. apart to allow for expansion when they become wet. Soaking of all wood with a suitable form oil or waterproofing compound is desirable in order to reduce water absorption by sheathing.

Forms should be constructed with slight draft, in the range of ⅛ to ½ in., particularly for the inside faces so that the distance between inside form and outside form is greater at the bottom than at the top. This taper may be applied to the inside or both faces of the form. The true wall thickness is measured at the elevation where hardened concrete is maintained in the form. This elevation may vary from 1 to 2 ft above the bottom of the form, depending on the form lifting speed and rate of concrete placement. The taper can be established through use of batter strips placed on the inside face of the upper set of wales. The taper reduces friction resistance to movement of the forms during jacking, and is extremely important to prevent the possibility of a mechanical blockage between concrete and sheathing during low speed periods (form "freezing").

7.3.2.2.2 Wales may be made of timber or metal. Two sets of wales are traditionally used, and they should be designed to hold the sheathing in place against lateral forces and friction forces, to transmit the lifting forces from the yokes to the form, (usually at the bottom waler) and to support various scaffolding and decks.

Both in the outside and inside form faces, diagonal and vertical bracing is placed between the two sets of wales thus forming a truss-like structural system responsible for the main vertical rigidity of the form.

Timber wales should be of 2- or 3-ply lumber at least one ply of which is nominal 2-in. material.

7.3.2.2.3 Lateral and diagonal bracing of forms must be provided to insure that the shape of the structure will not be distorted beyond allowable tolerances during the sliding operation.

7.3.2.2.4 The design of the yokes must provide for adequate clearance to install horizontal reinforcing bars and embedments in their correct locations prior to their submergence in the rising concrete. They should also be designed with a minimum of deflection to maintain the desired configuration and wall thickness. Bolted steel yokes have proven practical in most applications, however, they can also be made of timber. The spacing of the yokes must be planned with consideration for the reinforcing steel configuration, the location of openings, extreme loading points, and conditions of a similar nature.

7.3.2.2.5 A jacking system that provides for the simultaneous movement of the entire form in small increments of approximately 1 in. at 2- to 3-min intervals is recommended. This available jacking capacity may be desirable or necessary for short periods; forms do not usually maintain such speed of movement for extended times. Special care must be taken in choosing the capacity of the jacks and arranging them so that the forms will draw straight and true without strain or twist. Jackrods must be properly braced where not encased in concrete.

Due to the number of variables such as friction, working decks, and unbalanced loads, it is essential that reserve jacking capacity be provided in the system.

7.3.2.2.6 Working decks are supported directly on the forms and rise with them. The deck must be designed to maintain the plan dimension throughout the height of the structure. Through the use of trusses, corner bracing, tie rods, and similar items this can be accomplished.

7.3.2.2.7 Hanging scaffolds placed on both the outside and the inside form, provide the necessary access to finish the exposed concrete, and for the inspection of the form lower levels.

7.3.2.2.8 Drawings should be prepared by a competent and experienced engineer employed by the contractor, showing the jack layout, formwork, working decks, and scaffolds. A developed elevation of the structure should be prepared, showing location of all openings and embedments.

7.3.2.3 *Vertical loads*

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

Sheathing and joists . . . . . . 75 psf or concentrated buggy wheel loads, whichever is the greater
Beams, trusses, and wales . . . . 50 psf
Light-duty finishers' scaffolding . . . . 25 psf

7.3.2.3.2 The friction loads used in determining jacking requirements should normally be not less than 200 lb per linear ft of concrete wall when a nominal 3 ft 6-in. to 4-ft two-sided slipform is used.

7.3.2.3.3 Where working decks are used as a bottom form for further cast-in-place construction, such as floor slabs or roof slabs, the deck must be designed for the dead load of the concrete plus any superimposed loads, and in no case less than the design loads given in Section 2.2. Where the inside slipform becomes part of the slab system, attachment of the form to concrete must be designed to withstand the vertical and lateral forces associated with placing of the slab.

7.3.2.3.4 Vertical loads and torsional forces resulting from deck loads and friction must also be considered. The forms must act as trusses for the vertical loads between jacking points. Knee braces or other appropriate support systems should be provided for top wales where span between yokes exceeds 6 ft or where vertical loads are unusually heavy.

7.3.2.4 *Lateral pressure of concrete* — The lateral pressure of fresh concrete to be used in designing forms, bracing, and wales may be calculated as follows (see Appendix for metric conversions of equation).

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

where:

c_1 = 100*
p = lateral pressure, psf
R = rate of concrete placement in ft per hr
T = temperature of concrete in the forms, deg F

Wales' elements or plies must be adequately nailed or bolted together to transmit shear due to lateral pressure of concrete, and vertical posts should be placed between wales at lift points.

7.3.2.5 *Tolerances* — Suggested tolerances for slipform construction are listed in ACI 117.

7.3.2.6 *Sliding-operation* — 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 must be determined by an experienced slipform supervisor to accommodate changes in weather, concrete slump, initial set of concrete, and workability, and the many exigencies which arise during a slide and which cannot be predicted accurately beforehand. A person experienced in slipform construction must be present on the deck at all times during the slide operation.

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

The level of the hardened concrete in the form must be checked frequently by the use of a probe to establish safe lifting rates. Forms must be leveled before they are filled and must be maintained level unless otherwise required for out-of-tolerance corrections. Care must 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.

Alignment and plumbness of structure should be checked at least once during every 4 hr that the slide is in operation and preferably every 2 hr. 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 plummeting should be provided to readily detect and evaluate movements of the form for all slipformed structures so that appropriate adjustment can be made in sufficient time by experienced personnel.

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

7.3.3 *Horizontal slipforms*

7.3.3.1 *Design considerations* — For major structures, this specialized formwork should be designed by experienced, competent engineers employed or engaged by the contractor or form supplier. A complete structural analysis, including stress diagrams of the structural members, must be made to insure satisfactory performance. Due regard should be given to unsymmetrical and eccentric loadings and the fact that the machine must be regularly disassembled as it encounters siphons, bridges, chutes, etc. The large machines are usually hinged so that sections may be passed through or beneath structures. The vertical or lateral deflections, particularly of long-span machines, must be investigated, and sufficient rigidity provided to insure that concrete tolerances will be met. The stability of the machine under the aforementioned loading conditions must be carefully investigated to insure satisfactory performance.

7.3.3.2 *Drawings* — The general provisions of Section 2.1.4 should be met and the 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 insuring attainment of the required concrete surfaces.

7.4—Permanent forms

7.4.1 *Discussion* — Permanent forms, as the name implies, are forms left in place that may or may not become an integral part of the structural frame. These forms may be the rigid type 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 generally supported from the main structural frame with or without an intermediate system of temporary supports. If temporary supports are required under the structural frame members to support the weight of the fresh concrete without excessive deflection, such information should be specified by the engineer/architect.

7.4.2 *Design considerations* — If the permanent type form is not covered in the contract specifications, (1) the manufacturer's specifications should be used; (2) the

* It is felt that c_1 = 100 is justified because vibration is slight in slipform work since the concrete is placed in shallow layers of 6 to 10 in. and because there is no revibration. However, for some applications such as gastight or containment structures, additional vibration may be required to achieve maximum density of the concrete. In such cases, the value of c_1 should be increased to 150.

manufacturer's recommended practice* should be followed for size, span, fastenings, and other special features pertinent to this type of form, such as being water repellent and protected against chemical attack from wet concrete; and (3) the minimum requirements of Chapters 2 and 3 should be followed. Particular care should be taken in the design of such forms to minimize distortion or deformation of the form or supporting members under the construction loads.

The engineer/architect who specifies or permits the use of permanent rigid forms should consider in his structural analysis dead and live loads for the structure's intended usage, especially concentrated loads between supporting members.

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

7.4.3 *Installation*

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

7.4.3.2 *Fastenings* — The permanent deck form must be properly fastened to supporting members and to adjacent sections of form and properly lapped to provide a tight joint that will prevent loss of mortar during the placement of concrete. End closures for corrugated or fluted forms should be provided, where required, together with fill pieces where a tight fit is required. To prevent buckling, allowance should be made for expansion of metal deck forms.

Flexible types of forms (those that depend for lateral stiffness on supporting members) must be drawn tight for proper installation. Adequate temporary bracing or anchors must 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 reinforcement and to side or deck forms with wire ties or by other approved methods to prevent displacement or flotation during placing of concrete. End closures should be properly vented where necessary to eliminate cracking of concrete by reason of expansion of air in voids due to the heat of hydration of the concrete. Water should be prevented from entering voids. Where water intrusion is possible, weep holes should be provided to reduce its entrapment.

7.4.4 *Deflections* — The vertical and lateral deflections of the permanent form between supports under the load of fresh concrete should be investigated by the designer. Temporary supports should be used, if necessary, to keep deflection within desired tolerances.

7.5—Forms for prestressed concrete construction

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

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

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

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

7.5.2 *Design*

7.5.2.1 Where the side forms cannot be conveniently removed from the bottom or soffit form after concrete has set, such forms should be designed for additional axial and/or bending loads which may be superimposed on them during the prestressing operation.

7.5.2.2 Side forms that must 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 restraint to elastic shortening in the prestressing operation. For example, plan small components or wrecking strips that can be removed or destroyed to relieve load on side forms as well as to eliminate their restraint during prestressing. In all cases the restraint to shrinkage of concrete should be kept to a minimum, and the deflections of members due to prestressing force and the elastic deformation of form or falsework should be considered in the design and removal of the forms.

7.5.2.3 Care should be exercised with post-tensioned slabs to assure that supporting shores do not fall out due to lifting of slab during tensioning. For large structures where the dead load of the member remains on the formwork during prestressing, displacement of the dead load toward end supports should be considered in design of the forms and shoring including sills or other foundation support.

7.5.3 *Construction accessories* — Hold-down or push-down devices for deflected cables or strands should be provided in the casting bed or forms. All openings, offsets, brackets, and all other items required in the concrete work should be provided for in the formwork. Bear-

* If supported by tests by a recognized commercial testing laboratory.

ing plates, anchorage assemblies, prestressing steel, conduits, tube enclosures, and lifting devices shown or specified to be set in concrete must be accurately located with formwork templates and anchored to remain within the tolerances given on contract drawings and specifications. Quality and strength of these accessories should be as specified.

7.5.4 *Tolerances* — Suggested tolerances for job site precast and plant manufactured precast prestressed concrete members are given in ACI 117 and the PCI report on tolerances.*

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

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

7.6—Forms for precast concrete construction

7.6.1 *Discussion* — This type of form is used for precast concrete items that may be either load- or nonload-bearing members for structural or architectural uses.

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

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

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

7.6.3 *Accessories* — It is particularly important in this class of work that positive and rigid devices be used to insure proper location of reinforcement. All openings, cutouts, offsets, inserts, lift rings, and connection devices required to be set in concrete must 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 same will be exposed, will interfere with the proper placing of precast members or other materials, or will be subject to corrosion. Such items should be removed in such a manner that no remaining metal will be subject to corrosion.

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

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

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

Where required to allow early reuse of forms, provisions may be made to use accelerated curing processes such as steam curing, vacuum processing, or other approved methods.

Methods of lifting precast units from forms should be approved by the engineer/architect.

7.7—Use of precast concrete for forms

7.7.1 *Discussion* — Precast concrete panels or molds have been used as forms for cast-in-place and precast concrete, either as permanent, integrated forms or as removable, reusable forms. They have been used for both structural and architectural concrete, designed either as structurally composite with the cast-in-place material or merely to provide a desired quality of outer surface, and in some cases to serve both of these purposes. Concrete form units may be either plain, reinforced, or prestressed, 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 construction.

7.7.2 *Design*

7.7.2.1 *Responsibility for design* — Where the integrated form is to act compositely with the structure concrete, the form panel should be designed by the engineer/architect who should also indicate what additional external support is required for the permanent forms. For permanent forms intended principally to achieve a desired architectural effect, the engineer/architect may 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 contractor.

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

7.7.2.3 *Bonding concrete form to concrete structure* — Effective bond between precast form unit and the structure concrete is essential, and may 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; and (3) a combination of (1) and (2). Lifting hooks in a form unit may be designed to serve also as anchors or shear connectors.

7.7.2.4 *Code requirements* — Precast concrete forms used in composite design with cast-in-place concrete should be designed in accordance with "Building Code Requirements for Reinforced Concrete, (ACI 318)."

* "Tolerances for Precast and Prestressed Concrete," 1985, available from Prestressed Concrete Institute, Chicago.

7.7.3 During and after concreting

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

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

7.8—Forms for concrete placed under water

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

In the first approach, placement may be made by either pump, underwater bucket, or the more common 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 extends to the bottom of the area to be concreted. This pipe is charged with concrete from the surface, taking care to force any water from the pipe ahead of the concrete. Once the pipe is filled with concrete, it is kept full and its bottom must 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. The grout is introduced at the bottom and the water is displaced upward as the grout rises.

7.8.2 Underwater bucket and tremie

7.8.2.1 *Design* — Forms for underwater concreting are designed with the same considerations as other forms covered in Section 2.2 except that the density of the submerged concrete may be reduced by the weight of the water displaced. However, because of large pressures which can develop due to the head developed in the tremie, loads should be evaluated by personnel experienced in this type of work. Some designs have ignored the effects of submergence, because this results in a practical design which 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 may transform a planned submerged placement to one made above water, thus losing the offsetting water pressure.

7.8.2.2 Construction — Underwater forms should be built on the surface in large units insofar as possible, because final positioning and fitting when done underwater 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, insofar as possible.

Forms must be carefully fitted and secured to adjacent materials and/or construction to avoid loss of mortar under pressure developed. If there is any 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 may visualize and plan their work before descending.

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

7.8.3 Preplaced aggregate

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

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

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

CHAPTER 8—REFERENCES

8.1—Recommended references

Documents of the various standards-writing organizations whose procedures are recommended in this guide are listed below with their serial designation.

American Concrete Institute

116R Cement and Concrete Terminology

117 Standard Specifications for Tolerances for Concrete Construction and Materials

207.1R Mass Concrete

224R Control of Cracking in Concrete Structures

301 Specifications for Structural Concrete for Buildings

303R Guide to Cast-in-Place Architectural Concrete Practice

304.1R Guide for the Use of Preplaced Aggregate Concrete for Structural and Mass Concrete Applications

304.2R Placing Concrete by Pumping Methods

305R Hot Weather Concreting
306R Cold Weather Concreting
309.2R Identification and Control of Consolidation-Related Surface Defects in Formed Concrete
313 Standard Practice for Design and Construction of Concrete Silos and Stacking Tubes for Storing Granular Materials
318 Building Code Requirements for Reinforced Concrete
332R Guide to Residential Cast-in-Place Concrete Construction
344R Design and Construction of Circular Prestressed Concrete Structures
347.1R Precast Concrete Units Used as Forms for Cast-in-Place Concrete
359 Code for Concrete Reactor Vessels and Containments

American National Standards Institute

A48.1 Forms for One-Way Concrete Joist Construction
A48.2 Forms for Two-Way Concrete Joist Construction
A58.1 Minimum Design Loads for Buildings and Other Structures
A208.1 Mat-Formed Wood Particle Board

American Plywood Association

Plywood Design Specification, 1985

ASTM

A 446 Standard Specification for Steel Sheet, Zinc-Coated (Galvanized) by the Hot-Dip Process, Structural (Physical) Quality
C 532 Standard Specification for Structural Insulating Formboard (Cellulosic Fiber)

Canadian Standards Association

CAN3-086-M80 Code for Engineering Design in Wood

National Forest Products Association

National Design Specification for Wood Construction

U.S. Department of Commerce

LLB-810a Hardboard Concrete Form Liners (Simplified Practice Recommendation)
PSI-83 Construction and Industrial Plywood
PS20-70 American Softwood Lumber

These publications may be obtained from the following organizations:

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

American National Standards Institute
1430 Broadway
New York, NY 10018

American Plywood Association
P.O. Box 11700
Tacoma, WA 98411

ASTM
1916 Race Street
Philadelphia, PA 19103

Canadian Standards Association
178 Rexdale Blvd.
Rexdale, Ontario M9W 1R3
Canada

National Forest Products Association
1250 Connecticut Ave., NW
Washington, DC 20036

U.S. Department of Commerce
publications available from:
U.S Government Printing Office
Washington, DC 20402

8.2—Cited references

Additional information sources on which the committee recommendations are based are listed in Sections 1.5, 2.9, and 4.5.

APPENDIX—METRIC AND SI EQUIVALENTS

Equivalents of Imperial Units in Metric and SI

IMPERIAL	MKS METRIC	SI
1 inch (in.)	2.54 centimeters (cm)	25.4 millimeters (mm)
1 foot (ft)	0.3048 meters (m)	0.3048 meters (m)
1 pound-mass (lb)	0.4536 kilograms (kg)	0.4536 kilograms (kg)
1 pound-mass per cubic foot (pcf or lb/ft^3)	16.02 kilograms per cubic meter (kg/m^3)	16.02 kilograms per cubic meter (kg/m^3)
1 pound-force (lb)	0.4536 kilograms-force (kgf)	4.448 newtons (N)
1 pound-force per lineal foot (lb/ft)	1.488 Kilograms-force per meter (kgf/m)	14.59 newtons per meter (N/m)
1 pound-force per square inch (psi or lb/ft^2)	0.0703 kilograms-force per square centimeter (kgf/cm^2)	6.895 kilopascals (kPa)*
1 pound-force per square foot (psf or lb/ft^2)	4.882 Kilograms-force per square meter (kgf/m2) OR 0.0004882 kilograms-force per square centimeter (kgf/cm^2)	0.04788 kilopascals (kPa)

To convert temperature Fahrenheit (F) to temperature Celsius (C), use the formula $t_C = (t_F - 32)/1.8$.

* One newton per square meter is a pascal.

This report was submitted to letter ballot of the committee and was approved in accordance with ACI balloting requirements.

Conversions of nonhomogeneous equations

Section 2.2.2—*Lateral pressure of concrete (metric equivalents)*

$$p_M = 0.24h_{SI} \quad (2\text{-}1)$$

a. For columns

$$p_M = 0.073 + \frac{8.0R_{SI}}{T_C + 17.8} \quad (2\text{-}2)$$

(maximum of 1.47 kgf/cm^2 or $0.24h_{SI}$, whichever is least)

b. For walls, rate of placement not exceeding 2 m/hr

$$p_M = 0.073 + \frac{8.0R_{SI}}{T_C + 17.8} \quad (2\text{-}2a)$$

(maximum of 0.98 kgf/cm^2 or $0.24h_{SI}$, whichever is least)

c. For walls, rate of placement 2 to 3 m/hr

$$p_M = 0.073 + \frac{11.78}{T_C + 17.8} + \frac{2.49R_{SI}}{T_C + 17.8} \quad (2\text{-}3)$$

(maximum 0.98 kgf/cm^2 or $0.24h_{SI}$, whichever is least)

where

pM = lateral pressure, kgf/cm^2
R_{SI} = rate of placement, m/hr
T_C = temperature of concrete in the forms, deg C
h_{SI} = height of fresh concrete above point considered, m

Section 2.2.2—*Lateral pressure of concrete (SI equivalent)*

$$p_{SI} = 23.5h_{SI} \quad (2\text{-}1)$$

For columns

$$p_{SI} = 7.2 + \frac{785R_{SI}}{T_C + 17.8} \quad (2\text{-}2)$$

(maximum of 144 kPa or $23.5h_{SI}$, whichever is least)

For walls, rate of placement not exceeding 2 m/hr

$$p_{SI} = 7.2 + \frac{785R_{SI}}{T_C + 17.8} \quad (2\text{-}2a)$$

(maximum of 95.8 kPa or $23.5h_{SI}$, whichever is least)

For walls, rate of placement from 2 to 3 m/hr

$$p_{SI} = 7.2 + \frac{1156}{T_C + 17.8} + \frac{244R_{SI}}{T_C + 17.8} \quad (2\text{-}3)$$

(maximum 95.8 kPa or $23.5h_{SI}$, whichever is least)

where

p_{SI} = lateral pressure, kPa
R_{SI} = rate of placement, m/hr
T_C = temperature of concrete in the forms, deg C
h_{SI} = height of fresh concrete above point considered, m

Section 7.3.2.4—*Lateral pressure of concrete (metric equivalent)*

The lateral pressure of fresh concrete to be used in designing forms, ties, bracing, and wales may be calculated as follows:

$$p_M = c_1 + \frac{5.35R_{SI}}{T_C + 17.8}$$

where

c_1 = 0.05
p_M = lateral pressure, kgf/cm^2
R_{SI} = rate of placement, m/hr
T_C = temperature of concrete in the forms, deg C

Section 7.3.2.4—*Lateral pressure of concrete (SI equivalent)*

The lateral pressure of fresh concrete to be used in designing forms, ties, bracing, and wales may be calculated as follows:

$$p_{SI} = c_1 + \frac{524R_{SI}}{T_C + 17.8}$$

where

c_1 = 4.79
P_{SI} = lateral pressure, kPa
R_{SI} = rate of placement, m/hr
T_C = temperature of concrete in the forms, deg C

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